Commentary

SCOTS WHA HAE

'BRINGING in the New Year,' is an essentially Scots contribution to the legacy of our civilization. Certainly in Scotland the advent of the new year is still the great annual divide and Hogmanay is its preparation. To greet the new year regularly with such a real, active and stimulating zeal reveals surely a deep national optimism and vitality. The Scots have the reputation of being canny, systematic, responsible and hard-working; they are also supposed to be argumentative and litigious. But much is revealed by the form of national festivals; Scots have an annual stock-taking and rejuvenation.

Scotland is a relatively poor country. It has an area of some 30,000 square miles, a population of some four and a half millions and modest natural resources. The background is limited, indeed it is poor, and the Scots are proud of the part they have played and are playing in the world's affairs. They have every reason to be—and they are to be found everywhere. Gaelic is spoken in parts of Canada, and Dundee accents are preserved in New Zealand; Angus is an honoured family as well as a breed of cattle in the Argentine, the Carse of Gowrie is still the Eden-home to many active dwellers by the Pacific; Aberdonian accountants are still found in Peru and Chile has recently reminded us of the meaning of the name of Cochrane. Emigration has long been an important career in Scotland and there can be few families who do not have more blood relations 'furth of Scotland' than at home. This 'drainage of human resources' can reach the dimensions of a human blood-letting—as the Athenians discovered—and there is much evidence that for some two generations it has been excessive because the price in human skills, in brains and in initiative has been too costly. There have been signs for many years of a social anaemia; at present* about 40 per cent of Scottish graduates in science and 60 per cent in engineering leave Scotland.

The facts in human terms sound dramatic; they are. But this is only one aspect. Emigration cannot be prevented by fiat and indeed should not be prevented by fiat. All human enterprise requires three things—Men, Materials and Money. If the three legs of the tripod are out of balance, the seat is insecure and, inevitably, men are attracted to the focal centres of material development where the three are in harmony. The Scottish Council (Development and Industry) have recently set up an enquiry into resources for the future. This committee of eleven members has been set up to consider Natural Resources in Scotland in the widest context including people, land, water, fuel and energy, minerals, fish and wildlife and forestry. To study the present and potential resources of the country as a whole is both essential and exciting.

Ten years ago the United Nations Scientific Conference on the Conservation and Utilization of Resources drew attention to the obvious needs of countries first to know what their resources were and then how to make the best use of them. In a real sense all countries are 'underdeveloped' for industrial uses and social needs are continuously expanding and changing. In the United Kingdom there has been no such comprehensive conference; indeed the Scottish project is a new kind of enquiry, considered to 'provide the first forum of its kind outside North America'*.

The Scottish Council, which is privately supported by Local Authorities, industrial firms, banks, chambers of commerce, trade unions and private individuals, was established in 1946 and perhaps its first obvious success was in persuading the Government, the universities and industry to establish the Scottish Seaweed Research Association. A Mineral Resources Panel was established in July, 1948. 'Early in 1958 it was apparent that emphasis should be placed on the development of natural resources as a whole, animate as well as inanimate, as a means to improve the economic well-being of Scotland. In May 1959 a Committee on Natural Resources was formed to take the enquiry forward and as a result, a fact-finding study group will meet late in 1960'*. The broad programme, extending over four years, is: fact-finding in 1960, conference on action in 1961 and action in 1962 and 1963.

The project deserves every encouragement and will need every encouragement and practical help from all sections of the national life. The exploration must be both wide and deep. And in examining and seeking out the national assets, the primary purpose is to determine future action and assess the importance in *time* as well as place—of the multitude of necessary activities. Surely Scotsmen will not forget the place of money. The third leg of the tripod will certainly define the stability. Capital is the catalyst of action and capital on a national scale will be required.

The English should also give attention to these matters. The first start was made in the days of the Conqueror with the Doomsday Book. It is time the business was carried through.

* The Scottish Council, Castle Street, Edinburgh Papers M-80-10/A of December 4, 1959

PHOTOGRAPHIC PRODUCTION OF GRATINGS FOR MEASUREMENT

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THE moiré fringe technique for measuring displacement has attractive possibilities not only for the machine tool industry but also for the processing of scientific data. Dr BURCH describes three different photographic methods whereby it is hoped to produce the various types of grating that are needed.

IN RECENT years the diffraction grating, that familiar and often maligned tool of the spectroscopist, has found new and valuable application as a master scale for measuring displacement by the moiré fringe method[1–3]. This technique is based on the principle that, if a short 'index' grating and a long 'measuring' grating of similar pitch are mounted adjacent to each other on the two components whose relative movement is to be measured, then a simple optical system will produce a pattern of moiré fringes whose changes can be converted by a photocell into corresponding fluctuations of electrical current. These fluctuations are very nearly sinusoidal, and one cycle corresponds to a relative movement of exactly one grating spacing. If linear or radial gratings of sufficient accuracy are employed, then the sinusoidal signals can be processed to provide, in either digital or analogue form, an immediate and extremely precise measurement of length or angle.

The Moiré Fringe Technique

Moiré fringes formed by coarse absorbing gratings have long been used for monitoring changes of shape, but the possibility of using them for displacement measurement with the aid of electronic fringe counters has now assumed much greater importance. The sudden emergence and rapid growth of the latter technique has been precipitated by three main factors:

(*i*) The Merton–N.P.L. process, which was developed originally for spectroscopy by L. A. SAYCE, R. G. N. HALL, and G. D. DEW, and which ensured a plentiful supply of plastic replica gratings for linear measurement[4–10].

(*ii*) The fundamental optical conditions, formulated in connection with the same programme by Guild, for obtaining useful moiré fringes from transparent as well as from absorbing gratings of any desired pitch[1].

(*iii*) The universal trend towards digital methods of handling information, and in particular the development by Ferranti Ltd of a reversible photoelectric counter together with a complete electronic computing system for automatic machine tool control[11].

Moiré fringe measuring systems are now being used not only for several types of machine tool control but also for high speed digital processing of scientific data, as recorded for example on bubble-chamber photographs or on stellar or spectroscopic plates. For many recent linear applications a digital accuracy of one count per micron is required, and for certain goniometric purposes an angular accuracy better than one second of arc would be desirable. Until recently each demand for higher incremental accuracy made it necessary to use a grating with proportionately finer pitch, but this trend towards finer rulings may be reversed by a new electronic technique of fringe sub-division which is being developed at National Physical Laboratory in cooperation with Staveley Research Group[12]. The new counters will produce as many as twenty or even one hundred digits per fringe of displacement and should make it possible, in most applications, to operate with either 1000 or 100 very accurately spaced lines per inch. For such relatively coarse spacings the use of metal reflection gratings is an attractive proposition, and a pilot plant for continuous production of gratings on metal tape is being developed by Technicolor Ltd in collaboration with the N.P.L.

In most moiré fringe projects, the gratings and reading-head represent a small but essential measuring transducer surrounded by a complicated electrical and mechanical system, and close co-operation is needed between optical, electronic, and servo engineering experts if a satisfactory design is to be achieved. At the National Physical Laboratory the two objects which are being pursued are firstly to find the best method of reading and using moiré fringe signals, and secondly to ensure an adequate supply of all types of metrological grating. The National Engineering Laboratory, in addition to being at present the main producer of radial gratings, is primarily concerned with applying moiré fringes to the dynamic measurements and control of

machine tools. Both laboratories have encouraged the secondment of staff from all firms and research institutions that are themselves undertaking moiré fringe projects. At the National Physical Laboratory this arrangement has proved extremely effective; experts from other fields have had time to master thoroughly the special details of moiré fringe formation and adjustment, and in return have made important contributions.

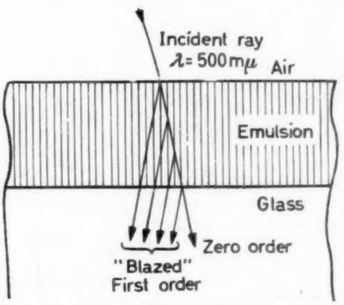

Figure 1. 'Interference filter' action of photographic gratings produced by direct interferometry—dispersion 30,000 lines per inch; emulsion thickness 0·005 in.

In 1957 it became clear that the demand for radial gratings, and also for very long and accurate but coarsely spaced gratings for use with the new counters, could not readily be satisfied by existing mechanical processes of ruling and replication. It was therefore decided to investigate in addition the possibilities of photographic production[13]. Three different photographic methods are being explored in this research, and the remainder of this article will describe the results so far obtained.

Direct Photography

In the direct interferometric method, a fine-grained photographic plate is used to record a stationary pattern of closely spaced fringes produced by a monochromatic light source in a specially designed two-beam interferometer. Since the fringe pattern invariably extends in depth throughout the whole volume of the emulsion, the result produced by development and processing is a series of layers of silver, or bleached silver, with clear gelatine in between. As will be seen below, experiments prove that this stratification corresponds extremely closely to the surfaces of maximum and minimum light intensity in the original fringe pattern, and one may therefore say that effectively the interference fringes have been 'frozen' into the photographic emulsion.

If the processed plate is now replaced in exactly its original position on the interferometer, but illuminated by *only one* of the two originally interfering beams, then it is easily shown that the three dimensional geometry of the 'frozen fringe' layers is such as to create, by diffraction and interference, a disturbance exactly resembling the missing beam (*Figure 1*). Because of this, and with a suitable pair of coherent beams, almost any type of diffracting grating or zone-plate can be generated photographically. To produce useful metrological gratings, however, a very large number of uniformly spaced fringes is required, and a discharge lamp of high spectral purity must therefore be used. The faintness of such lamps, coupled with the relative insensitivity of fine-grained emulsions, makes it imperative to choose an efficient interferometer operable with a large circular source rather than a narrow slit.

Figure 2 shows an arrangement which fulfils these requirements. It will produce transmission gratings about 3 in. square, with a spacing that can be adjusted from 11,000 up to 60,000 lines per inch by altering the obliquity with which the two interfering beams intersect on arrival at the photographic plate *P*. With such an instrument extremely poor definition is obtained unless the fringes are localized in the immediate vicinity of *P*, but correct adjustment of the mirrors is readily obtained by means of the following null interference technique. A fully aluminized reflector is mounted in the kinematic location normally occupied by *P*, and each of the two incoming beams is thereby returned to the source via the path already traversed by its fellow. The returned image of the source, which can be observed by interposing an auxiliary beamsplitter between source and collimator, is seen covered by a pattern of 'enantiocyclic' fringes (produced by two beams which have traversed identical cyclic paths but in opposite directions), and the interferometer mirrors must then be adjusted until all the enantiocyclic fringes have disappeared. This operation ensures that the fine fringe pattern is correctly localized, and the only further precaution before commencing an exposure is to check that the source is being imaged back on to itself and is of a diameter appropriate to the fringe pattern being recorded.

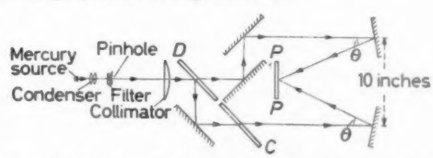

Figure 2. Interferometer for generating fine transmission gratings and for testing emulsion performance—3 in. aperture, dispersion between 12,000 and 60,000 lines per inch; fringe spacing is $\lambda/2 \sin \theta$, adjustment by enantiocyclic white light; D is the dividing plate (BiO coating); C the compensating plate; and P is a photographic plate

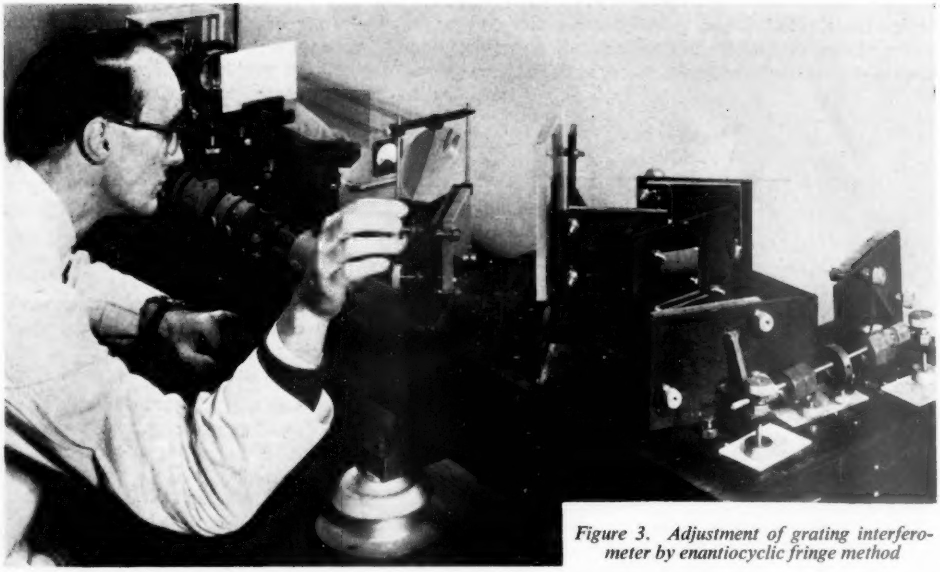

Figure 3. Adjustment of grating interferometer by enantiocyclic fringe method

If N is the total number of well-defined fringes required, the solid angle subtended at P by the circular source should not exceed π/N steradians. *Figure 3* shows these adjustments being completed by Mr F. C. MIDDLETON, who has been responsible for much of the work on this and the second method.

Results Obtained

Early experiments successfully employed plates coated with Dr CRAWFORD's Lippmann-type emulsion[14], but it was found later that commercially obtainable Kodak Maximum Resolution plates will resolve 60,000 fringes per inch and give excellent stability of the emulsion during processing. The illuminant employed is mercury green radiation, obtained either from a Siemens miniature M1 lamp, run at about 0·6 amps steady current, or from an Hg^{198} electrodeless discharge operated in air at 250 Mc/sec. A Kodak MR plate used with the former source will record about 50,000 well defined fringes in an exposure time of 30 minutes, but to record a million fringes would be extremely difficult because of low intensity reciprocity failure.

Transmission gratings have been produced with various spacings up to about 57,000 lines per inch, but their spectroscopic possibilities are limited by considerable absorption and scattering and by inhomogeneity of the glass support. For measuring purposes also the pitch of these gratings is inconveniently fine, and perhaps the main value of this interferometer has been the searching test of emulsion stability which it has provided.

If a processed plate is replaced on the interferometer and illuminated by *both* the interfering beams, then a moiré fringe pattern can be observed which delineates the slightest discrepancy in shape between the optical fringe pattern, which is still being generated by the interferometer, and the 'frozen' fringe pattern recorded by the emulsion. As a result of such 'before and after' checks, supplemented for coarser spacings by photoelectric measurement, it is now known that normal processing of a grating image recorded on Kodak MR emulsion does not introduce lateral shifts or distortions greater than two or three microinches. This information is vital to all photographic projects for grating production, and makes it worth while to consider very carefully the other sources of error to which each method is liable.

New Interferometer for Large Apertures

The arrangement of *Figure 2* is suitable only for producing small gratings of very fine spacing, but a much smaller solid instrument which has recently been constructed (*Figure 4*) will be located at the focus of a large collimating lens or mirror, and will thereby produce relatively coarse fringe patterns across very large apertures. Dr D. A. PALMER has completed preliminary trials with a collimator of 4 inches diameter, and a collimator 18½ inches in diameter is now being installed. A range of spacings from 700 lines per inch up to about 4000 lines per inch is contemplated, and some interesting spectroscopic possibilities are also envisaged.

Copying and Correction of an existing Master Grating

The Merton–N.P.L. processes are well adapted for producing large numbers of linear gratings up to ten inches long, but longer gratings, for which the demand is increasing, are made at present only by joining several resin sections in correct relative phase, an operation which needs considerable care and skill[10]. The interferometric work described above suggested that for these longer gratings photographic methods might be satisfactory, and a travelling printing frame has been developed for copying an existing master up to 3 ft. long (*Figure 5*).

In this apparatus the master grating is lightly held, by means of several clamps and spacers, against a long photographic plate, and the sandwich so formed is traversed on a moving carriage, at a speed of about two inches per minute, past a steadily shining collimated beam from a high pressure mercury lamp. This beam is about half an inch wide, so that each portion of the sandwich in turn receives an exposure of about 15 sec. the brightness at λ 5461 Å being adjusted by filters to suit the Kodak MR emulsion.

Spacing of Sandwich

In this copying process the master may be either a wedge-shaped transparent ruling or a photographic absorbing grating, but in each case the thickness of the spacers must be adjusted to bring the photographic emulsion into a region where the Fresnel diffraction produced by the master has good intensity modulation. For a transparent grating the correct spacing takes the form $[(n - \frac{1}{2})w^2]/\lambda$ where w is the grating spacing, λ the wavelength of illumination, and n a positive integer. For a photographic master, whose surface usually contains some phase corrugation, the spacing required is approximately $[(n - 0{\cdot}1)w^2]/\lambda$ but it is best to determine this by trial exposures. In present work at 1000 lines per inch the wedge-shaped master which contains four phased-up resin sections, each nine inches long, is used with a spacing of 0·023 inch to give any number of copies. Because of the fine grain and high contrast of the MR emulsion, each of these copies has a perfectly defined ' line and space ' pattern, and will itself give further exactly similar second generation copies provided that the spacers are changed to 0·042 inch thickness.

Copying at 2500 lines per inch is also easy, but for pitches between 4000 and 8000 lines per inch the tolerances on spacer thickness become difficult to satisfy. At 10,000 lines per inch and above, the blaze effect produced by Bragg reflection (see *Figure 1*) means that all the emergent light is shared between the zero order and preferred first order beams; the result is a two beam fringe pattern for which spacing is no longer critical, and satisfactory copies have for example been obtained by printing from a small ' interferometric ' master with 23,000 lines per inch.

Moiré Fringe Performance

The fringes produced by ' line and space ' gratings are satisfactory as regards their profile, but about six times less bright than those produced by the best wedge-shaped rulings. For coarser pitches this does not matter, but for 1000 lines per inch and above the preferred solution is to use polyester resin replicas which have been taken from the sinusoidally corrugated gelatine surface of the photographic copy. With these transparent tertiary replicas the loss of brightness is no longer significant, and extremely pure sinusoidal fringes can be obtained.

Correction for Known Progressive Error

Because of the small but finite separation of the copy from the master, a relatively large change in the direction of the beam hitting the sandwich produces a very small lateral displacement of the image being

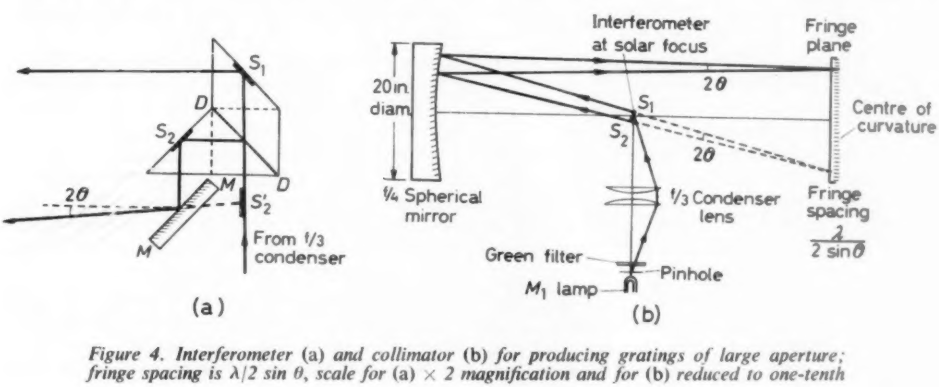

Figure 4. Interferometer (a) *and collimator* (b) *for producing gratings of large aperture; fringe spacing is $\lambda/2 \sin \theta$, scale for* (a) $\times$ *2 magnification and for* (b) *reduced to one-tenth*

recorded on the copy. It is therefore possible during the exposure to correct for any known progressive errors of the master by appropriately controlling the direction of illumination. On the printing frame shown in *Figure 5* this is achieved very simply by

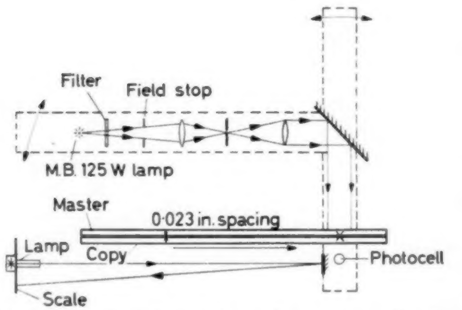

Figure 5. Travelling printing-frame for calibrating copying and correcting long metrological gratings

pivoting the entire optical bench, which carries the illuminating system, about a point X vertically below where the light hits the sandwich; movement of this bench is controlled manually, and measured by a lamp and scale arrangement, to within something like five microinches of effective error.

Calibration of Master

A bench for directly calibrating the master against a known line-standard will shortly be available, but some success has been obtained meanwhile with an internal method carried out *in situ* on the printing frame by means of an ORP 90 cadmium sulphide photocell. This technique involves sandwiching the master together with a somewhat shorter grating (usually an uncorrected copy of the master), and measuring the brightness of the resultant 'fluffed-out' moiré fringe pattern. By pivoting the bench about X a sinusoidal variation of output current is produced, and the phase of the moiré pattern for the half inch wide illuminated portion of the sandwich can be measured to within 0·005 of a fringe. By measuring various portions of a given sandwich, and then repeating the measurements for a different relative position of the two gratings, considerably more observations are accumulated than are needed to establish the unknown errors of the two gratings. A least-squares solution is easily extracted by a calculation similar to that used for calibrating line-standards, and some idea of the consistency of the method is given by the residuals[15].

Mr Middleton has found that calibrations by this method, and the removal of calculated error during a subsequent travelling exposure, are both liable to an r.m.s. residual error of about ten microinches. It is very easy however, for systematic errors much greater than this to arise, caused for example by clamping together two imperfectly flat pieces of glass. Error due to differential flexure is minimized by mounting both master and copy on glass blanks of the same width and thickness, and by ensuring that no external couples can act upon the sandwiched pair. Indications are that a real accuracy of ten microinches per foot may be obtainable, but this can only be confirmed by external checks.

Apparatus also nearing completion will enable very similar processes of internal calibration, copying, and correction to be applied to an existing radial grating.

Since the printing beam is half an inch wide, the correction process deals only with 'slow' progressive errors of the master, and has little or no effect in reducing periodic errors which repeat themselves several times per inch. In most systems this does not matter because the long measuring grating is scanned by means of an index which is itself about half an inch wide, and the surviving rapid errors are averaged out and eliminated during the reading process.

Nevertheless, in the compact reading-heads which are being designed to divide each fringe into one hundred parts, it will be unwise to place too much reliance on this averaging principle, and it will be better to use more perfect masters produced by the methods of the next section. The printing frame will then be given the humbler but important duty of producing from such masters as many straightforward copies as are required.

Self-correction by Moiré Fringe Control

The methods of calibration and correction just described are somewhat laborious, but have been given priority of development because they can be brought into operation quickly and without precisely constructed apparatus. Preparation is now being made, however, for a more fundamental project in which grating errors are eliminated automatically by an iterative 'breeding' process. At each stage the eugenic principle employed is that a photocell is made to average the errors of two imperfect 'parent' gratings in such a way as to control electrically the photographic recording of a much better grating. It is hoped that this method will ultimately provide linear and radial masters of almost any chosen periodicity, residual error being governed mainly by the stability of the material used to support the grating.

This method has not yet been brought into operation, but *Figure 6*, which is a simplified diagram of apparatus now being constructed, illustrates the principles involved in the case of radial gratings.

(*i*) An accurate spindle rotates very slowly, carrying with it an imperfect radial grating *A* and an unexposed photographic plate *C*.

(*ii*) Immediately above *A* is a similar but stationary grating *B* and an optical system which collects and feeds on to a photocell the fluctuations of moiré

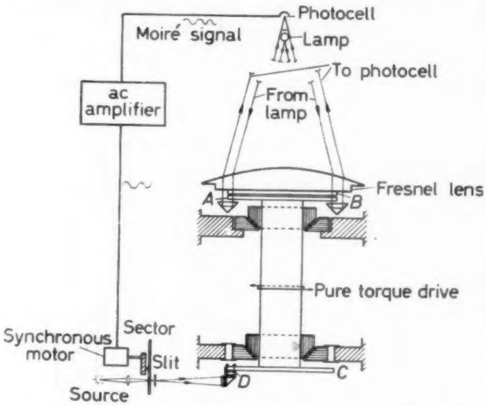

Figure 6. Production of radial gratings by moiré fringe control; an integrated signal, formed by imperfect grating, θ, A and B, controls the printing of a small grating D on to the photographic plate C

fringe intensity from the entire annular periphery of *A* and *B*. The fringe pattern is of course ' fluffed-out ' as far as the grating errors permit.

(*iii*) *If it can be assumed that errors of centring, and the residual errors of A and B, do not exceed one quarter of a fringe, then integration at the photocell produces a well-defined periodic signal which is much more regular than would be obtained by scanning either A or B by means of a single slit.*

(*iv*) The smoothed photoelectric signal is amplified and used either to trigger an electronic flashtube or to rotate a synchronous motor and light-chopping sector. Each flash of light is used to print a small portion of a stationary radial grating *D* on to the plate *C*, and a composite pattern is thus built up from a very large number of overlapping images.

(*v*) If the parent gratings *A* and *B* are averaged round their entire periphery, then the new grating *C* obtained after processing should be substantially free from error, but if necessary two such improved gratings can be used to supersede the original pair, and the whole cycle of operations is then repeated.

(*vi*) By introducing gears between the synchronous motor and sector, or by suitable electronic circuits, a change of spacing between *C* and its parents is readily introduced; in this way finely spaced masters can be derived from crudely spaced originals, and composite gratings with multiple binary or decimal tracks can also be recorded.

The most important feature of this technique is the use of a photocell to average the local irregularities in a moiré fringe pattern produced by imperfect gratings; the error-smoothing process is in fact a photoelectric version of the elastic averaging which is performed on a helical ruling by a resilient Merton nut. Photoelectric averaging has always been a valuable feature of the moiré fringe reading-head, and what is being done here is to carry this idea to its logical conclusion by using an index grating which is as long as possible. A concise mathematical description of the process can be given in terms of the convolution theorem for Fourier Transforms[16], and has been discussed at length elsewhere[3,13].

Conclusion

It should be emphasized that the work described above has been largely preliminary, but the interferometric results on emulsion distortion encourage the hope that sooner or later, and especially with the cooperation now being received from industry, a plentiful supply of accurate photographic gratings will be achieved.

Research on grating production in Light Division has been guided throughout by Dr L. A. Sayce, and patent applications in respect of the new photographic methods have been assigned to the National Research Development Corporation. The author is grateful to the Director of the National Physical Laboratory for permission to publish the figures, for which Crown copyright is reserved.

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AN ATOMIC STANDARD OF LENGTH

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The proposal, to be put forward in 1960 to the Conférence Générale des Poids et Mesures, to adopt a wavelength of light as the world's new standard of length is the outcome of an idea originally proposed by Lamont in 1823. The major aspects of this idea are discussed. Events and early difficulties leading up to the reality of an unalterable atomic standard of length and the ramifications are dealt with.

ONE OF the results of atomic research which has not received anywhere near as much publicity as the atom bomb but which ranks with it in importance as far as the peaceful applications of atomic developments are concerned is the exciting possibility of redefining our present length standards in terms of what is in effect an atomic standard of length. This standard is the wavelength of light emitted by certain man-made atomic isotopes of well known elements.

Prototype Metre Bar

At present the prototype metre is the standard unit of length and is, by definition, the distance between two lines engraved on a platinum–iridium bar kept by the *Bureau International des Poids et Mesures* at the Pavillon de Breteuil, Sèvres, and this length is taken to be invariable by hypothesis. Sub-standards or secondary standards taken from the primary standard are, of course, widely used but the fact remains that this platinum–iridium bar alone defines the length of a metre and all measurements of length throughout the world are finally referred to this single standard.

There are two clear disadvantages inherent in this type of standard. Firstly, although the prototype metre bar seems so far to have preserved its first class qualities, it is only by hypothesis that its length is invariable and there is the distinct possibility of a small change in the length of the bar brought about by the continual ageing of the material with time. Secondly there is only this one bar in existence which actually defines the length of the metre and although it has survived the ravages of two world wars it would be of the utmost temerity to assume that it would necessarily survive an atomic war.

Another disadvantage which requires more detailed knowledge of the bar itself, is that one of the greatest inaccuracies associated with the metre standard is due to the physical nature and finite width of the engraved fiduciary lines, the distance between the centres of which is the standard length of one metre. Although some metrologists claim that they can intercompare another secondary line standard with this primary line standard, as it is called, to within one or two hundred thousandths of a centimetre, examination of the fiduciary lines under a high power microscope shows that this accuracy probably cannot be attained with reliability. What is observed as a sharp line at lower magnifications is in fact more of a diffuse type of pattern called a diffraction pattern than a well defined image and its appearance will vary with the conditions of illumination. This situation results from the way in which the illuminating light is reflected at the inner surfaces and edges of the grooves of the fiduciary lines. There is some hope that by removing the human element in these observations the accuracy will be improved. This may be brought about by the use of a newly developed instrument called the photoelectric line setting microscope but the fundamental physical problem of diffraction still remains.

Nevertheless the prototype metre bar is the primary standard and has been accepted as such by all of the countries of the world for over seventy years and all precision measurements of length and associated quantities have been based on it. In fact in 1927 the *Conférence Générale des Poids et Mesures* used it to define a fundamental standard of light wavelength measurement as the wavelength of the red light emitted by the element cadmium under certain specified conditions with the value $6438{\cdot}4696 \times 10^{-10}$ metre. This decision was brought about largely by the results of the researches of the American physicist Professor A. A. Michelson into the purity of light sources.

Measurement of Length by Light Wavelengths

Michelson's work was aimed at obtaining an accurate determination of light wavelengths and his measurements were made in Paris in 1893 in co-operation with the French physicist Benoît. Despite long researches Michelson found that the red light emitted by the element cadmium was the only light sufficiently pure, or sufficiently monochromatic to express it more scientifically, to be used in their measurements. These measurements consisted of

two main parts. The first was the determination of the number of wavelengths in a specially designed standard of nominal length ten centimetres.

The measurement was made using a light wave interferometer, which is a relatively simple optical apparatus but which nevertheless is capable of an amazingly high accuracy in measuring the number of light waves in a given length. The instrument relies in its operation on the fact that two identical waves cancel each other if they are out of phase by half a wavelength and produce what is called an interference 'fringe'. Light waves reflected at each end of the length standard being measured are recombined and the number of wavelengths by which they are out of phase is found from the number of fringes produced and is a measure of the number of wavelengths in the length considered.

The second part of the experiment was the comparison of the ten centimetre standard with the working standard metre which in turn was compared with the national standards and these were compared finally with the prototype metre by means of travelling microscopes in an arrangement termed a line comparator. Thus, accepting the primary standard as one metre, a value for the wavelength of the red light of cadmium could be found. The final value of this wavelength was $6438{\cdot}4722 \times 10^{-10}$ metre. To take account of the humidity of the air, a later correction was made by Benoît and reduced the value to $6438{\cdot}4695 \times 10^{-10}$ metre in dry air at 15°C and 760 mm pressure. A new determination was made in 1906 by Benoît, Fabry and Perot in Paris using a more accurate type of interferometer. The result of this determination was $6438{\cdot}4696 \times 10^{-10}$ metre and was the final value accepted in 1927, as mentioned earlier, by the *Conférence Générale de Poids et Mesures* as the standard of light wavelength.

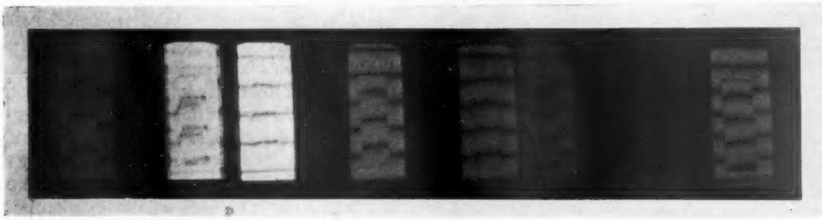

Figure 1. Interference fringes at several different wavelengths of cadmium light, used to measure a slip gauge. The gauge is seen as a small rectangle over the base platen. The displacement of the fringes between the platen surface and the gauge surface corresponds to the change in path length of the light rays reflected from those surfaces and from which the length of the gauge can be found. Each light wavelength present in the light gives a separate pattern, as shown, and the fringe displacements are correspondingly different for each wavelength, since the distance between successive fringes corresponds to a change of half a wavelength. Note the double fringe pattern on the second image, due to the presence of a doublet.

Because of this decision all of the measurements of wavelength in spectroscopy and in many other branches of science are perfectly comparable throughout the whole world. This also applies to the end standards and slip gauges used in industry for precision measurement and gauging, because all of these can be measured or calibrated in terms of light waves in an interferometer as done by Michelson. *Figure 1* shows interference fringes on a slip gauge taken in an actual precision determination of length. The fact that we can standardize these gauges by using light waves in this way and that this can be done independently and separately all over the world, the results being perfectly comparable because of the definition of the standard wavelength, suggests that the wavelength of light is itself more of a primary standard of length than the distance between two lines on a man made bar.

Necessity for New Standard

The first suggestion that light waves could be used as standards of length was actually made by the French physicists Lamont in 1823 and Babinet in 1827 but the accuracy of wavelength measurements on the apparatus of that day was not sufficiently high for the suggestion to warrant practical consideration. The desirable qualities of such a wavelength standard were pointed out again and in more detail by the physicist J. C. Maxwell in the year 1870. Maxwell explained that if we desire a standard of length or time or mass of an absolute permanence we should not rely on the dimensions nor on the movement nor on the mass of our planet but should use quantities associated with the atom, since atoms are imperishable, unalterable and perfectly alike for any particular element. Thus the length of light waves emitted by an atom when in an excited state could be used as a unit of length, the period of an atomic vibration

and the mass of some atom could be used as the units of time and mass respectively.

Maxwell showed ingenious foresight for it was later established that the speed of rotation of the earth is indeed diminishing and its size possibly changing whereas the atoms of any particular element are absolutely identical. However Maxwell could not foresee the enormous complexity governing the emission of light from these atoms and it was necessary for the famous theories of quantum mechanics developed by Bohr, de Broglie, Heisenberg, Schrödinger and Dirac to render physically comprehensible the new discoveries that experimental methods made possible and to show conclusively that Maxwell's propositions were mathematically and indisputably correct.

Purity of Wavelengths

These results gave more weight to the practical consideration of the wavelength of light as a unit of length but it must be remembered that Michelson found only one wavelength sufficiently monochromatic to warrant use as a standard and even today from among over three hundred thousand known atomic wavelengths emitted by the elements only fifteen are suitable for such purposes. This is because the light emitted at the nominal wavelengths from most atoms is not concentrated at one central wavelength but actually covers a very small but finite range of wavelengths and is therefore not absolutely pure. Even the cadmium red light is not perfectly monochromatic but until recently was the purest light available.

The magnitude of the natural inhomogeneity in radiated light waves is very varied but is extremely small for certain radiations such as the red light of cadmium. It decreases with decreasing temperature but even at the very lowest temperatures the atoms of a source of light are still in a state of unavoidable thermal agitation and the movement of the atoms contributes a certain inhomogeneity to the radiated waves and is known as the Doppler broadening. Each radiation emitted by an atom in reality occupies a small portion of the wavelength spectrum in which the intensity varies as a function of the wavelength according to a symmetrical curve in the shape of a bell and is referred to as a spectral 'line' *Figure 2a*. The symmetrical shape of the curve defining the spectral line enables the mean wavelength to be given without ambiguity. Also in a source of light each atom is under the influence of both the electric field of the neighbouring atoms and the applied electric field necessary for excitation in the discharge tube. These fields broaden the lines in an asymmetrical way such that the mean wavelength is increased. It is therefore necessary to produce the light by an electric discharge in a rarefied gas and with a weak electric current. Even so the most monochromatic waves are always of the lowest intensity and in addition it sometimes happens that the colder atoms neighbouring the inner walls of the discharge tube which are in a lower energy state are capable of absorbing energy radiated from the more excited atoms and the desirable main central part of the original bell-shaped line is absorbed leaving a line called a doublet, having two peaks on either side of the central region. In such unfortunate cases the line is said to have undergone 'self-reversal'.

Until recently other grave defects appeared inevitable. Due to the structure of the atomic nucleus spectral lines of many atoms have what is termed hyperfine structure, which means that the spin of the nucleus has an adverse effect on the purity of the light which such atoms can emit such that the usual symmetrical bell-shaped line is split into several closely spaced finer lines which together give rise to a more impure radiation than when this hyperfine structure is not present *Figure 2b*. The effect is not present for atoms having zero nuclear spin and this condition occurs in an atom having a nucleus containing a number of pairs of protons and neutrons or, in other words, an element of even atomic mass number since the mass of a proton is the same as that of a neutron. However, many elements which might be suitable as light sources contain a mixture of both atoms with zero nuclear spin as well as those without. Such atoms are known as isotopes of the element concerned and were until recent years, not easily separable in practice.

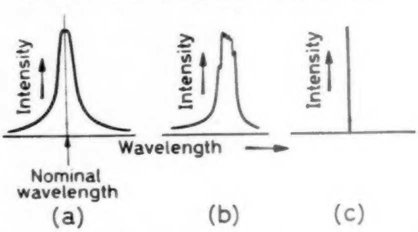

Figure 2. The finite spread of actual spectral lines: (a) *exaggerated form of typical spectral line showing the spread of the line on either side of the central nominal wavelength;* (b) *spectral line showing fine and hyperfine structure;* (c) *ideal spectral line with no spread on either side of nominal wavelength.*

Use of Isotopes

Between the years 1940 and 1942 events took place which were to hasten the practical consideration of a wavelength standard of length. These events were the production of an isotope of mercury of atomic

mass number 198 by bombardment of gold of atomic mass number 197 with neutrons in an atomic pile, and also the successful separation of isotopes of krypton of atomic mass numbers 84 and 86. This permitted the total elimination of the inhomogeneity due to hyperfine structure in the light emitted from atoms of these isotopes of krypton and mercury and the nature of the atoms is such that the emitted radiation is so monochromatic that an increase by a factor of at least ten in the accuracy of length measurement using these light waves was made possible.

The light from these atoms is almost three times as pure as that of cadmium red light and is reproducible in any laboratory at any time with an accuracy in the wavelength measurement of one part in one hundred million and provides the possibility of defining the metre with an accuracy of at least ten times better than the actual platinum–iridium bar with a subsequent increase in the accuracy and reproducibility of precision measurements throughout the world. In addition the existence of these light waves is not dependent on any perishable or alterable material standard.

If the roles of the present secondary standard (wavelength) and primary standard (prototype metre bar) were to become interchanged, a declaration by the *Conférence Générale des Poids et Mesures* analogous to its ruling of 1927 would fix the length of the platinum–iridium prototype metre bar in terms of a certain wavelength of some particular suitable element and would ensure that the uniformity of all the world's line standards would continue as before. It is for the specialists and official standards laboratories of the world to make a decision as to whether the metre should be redefined in terms of a wavelength of light.

Comparison of Suitable Isotopes

Before such a final decision is made it is necessary to choose between mercury–198 and the isotopes of krypton as regards such matters as relative purity of the radiations and convenience of operation of the respective discharge lamps. The spectral lines of mercury–198 are less fine than those of the krypton isotopes but we can produce them at ordinary temperatures and they are more intense and more easy to isolate than those of krypton. The temperatures of the light source must be as low as possible, as has been pointed out previously, but must be sufficient to attain a certain vapour pressure in the lamp. Comparing cadmium, mercury–198 and krypton–84 discharge lamps, the optimum operating temperatures are 287°C, 0°C and − 10°C.

Another point of comparison relates to the maximum length which can be measured by these waves in an interferometer. When the distance being measured passes a certain limit the interference fringes become progressively fainter and eventually disappear. This is a result of the slight inhomogeneity present in all wavelengths due to the width of all spectral lines which, although very small for the isotopic sources mentioned, is nevertheless finite. The maximum distance which can be measured by light waves is of the order of 250 mm for a cadmium source, 500 mm for a mercury–198 source and 800 mm for a krypton–84 source cooled to − 210°C. Thus, although an increase in purity by a factor of three has been obtained it is still not possible to measure a distance of one metre directly by interferometry. However there are methods of addition and multiplication which allow us to measure a one metre standard by light waves by using smaller standards of a half or a quarter of a metre for example, in a similar way to Michelson in his 1887 measurements without increasing the relative error of the determination.

It is necessary of course to choose one particular wavelength of one of the isotopes as the fundamental standard. The green spectral line of mercury–198 has been proposed and is very bright but unfortunately suffers self-reversal easily, whilst the violet line of the same isotope is much less intense but is quite easy to photograph and does not undergo self-reversal. In the spectrum of krypton the respective qualities of three main wavelengths have been discussed by research workers. A conventional value must be given to the spectral line eventually chosen such that the length of the metre resulting from this new definition is the same as the original. Also it is necessary to choose between the value of the chosen wavelength in vacuum or in air under standard conditions, and in addition, the conditions of excitation must be specified.

The major standards laboratories of the world have tested and compared various isotope lamps of different design with regard to the several points just discussed. The results obtained have been considered by an international advisory committee which decided to recommend the orange line of krypton–86 as the means for future definition of the metre. On this basis the metre is equal to 1,650,763·73 vacuum wavelengths of the radiation, the corresponding value of the wavelength being $6057{\cdot}8021 \times 10^{-10}$ metre. A recommendation to adopt this definition will be submitted for the approval of the *Conférence Générale des Poids et Mesures*, which meets in October, 1960, and will then decide whether to preserve as our primary standard the man-made platinum–iridium prototype bar or accept a new primary standard of length which is, moreover, as old as time itself.

CHEMISTRY AND CLOTHING

H. A. THOMAS

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After briefly classifying the different types of fibre Dr THOMAS describes the production of viscose and the various finishes used to confer different properties. He outlines the merits of regenerated cellulose fibres and describes the advantages of blending viscose rayon staple with other fibres. In the appendix he tabulates the U.K. and world-wide consumption of different fibres.

IN THE interest of rational progress in the clothing industry, it is essential that there is closer co-operation between scientists of the man-made fibre producers (or chemical fibres industry, as it is known in Germany and Japan), and technologists of the garment making sections (' confection ') of the textile trade. A sufficiently wide range of textile fibres is at present available to enable most specific requirements of the clothing industry to be met. The clothing manufacturer should, therefore, when creating new styles and types of garments specify as precisely as possible the properties of the fabrics required to realize his concepts, in terms of performance (or properties), comfort, quality and price.

Classification of Fibres

Such a procedure concerns the basic properties of fibres, yarns and fabric structure, and requirements may have to be met by mixing fibres possessing complementary properties. Specifications relating either to natural or man-made fibres *per se* become meaningless, because no two fibres possess the same combination of properties. The natural fibres differ from one another as widely as do the different man-made fibres. All are derived from natural sources, and when they are in the form of clothing, they have all passed through chemical and physical processes, including bleaching or dyeing and finishing, crease-shrink- or water-proofing, durable pleating, minimum-ironing or drip-dry finishing. In use, therefore, the so-called natural fibres are no longer in their natural state.

Water-absorbing (hydrophilic), or oil-absorbing (lipophilic) power is an intrinsic property of a textile fibre and this quality is usually associated with other properties such as absorption of perspiration, soiling, chemical reactivity and suitability for laundering, dry-cleaning and dyeing. It is convenient, therefore, to classify fibres in order of their water of imbibition. When a mass of fibres is saturated in distilled water at 25°C and centrifuged at 1000 *g* for five minutes, the total molecularly-held water is expressed as a percentage of the weight of fibre. The commercially available fibres cover a wide range from cuprammonium rayon at 120 per cent to *Terylene* at 3 per cent (*Table 1*).

Table 1

Fibre	*Water absorbed as percentage weight of fibre*
Standard viscose rayon	100 (approx.)
Wool	40 (approx.)
Cotton	50 (approx.)
Cellulose diacetate (*Dicel*)	35
Cellulose triacetate (*Tricel*)	10–16
Polyacrylic (*Courtelle*)	8
Polyamide 66 (*Bri-nylon*)	11
Polyester (*Terylene*)	3

The regenerated cellulose fibres are therefore the most highly water absorbent fibres available, and in this respect complement the so-called synthetic polymer fibres, polyamides, polyesters and polyacrylics.

The Viscose Process

Recent advances in the chemistry and physical chemistry of cellulose and of the viscose process have resulted in the production of completely new cellulosic fibres with a strength of almost three times that of standard viscose rayon and with a lower water of imbibition—almost half that of standard viscose rayon. Different combinations of properties, including strength, resistance to abrasion, water absorption, extensibility when wet, resistance to shrinkage, crimp or waviness can be achieved by control of the viscose process of regenerating cellulose. These new cellulosic fibres should not be regarded as modified viscose rayons. They are fibres in their own right, just as cotton is.

In 1904 viscose filaments had a tenacity of 1·0 g per denier; in the decade 1920–1930, standard viscose filaments possessed a tenacity of about 2·0 g per denier. The present strength of Courtaulds' standard viscose rayon staple—*Fibro*—is 2·5 g per denier, and strong viscose rayon staple—*Strong Fibro*—is 3·5 g per denier; *Fibre M95* is 4·2 g per denier and *Tenasco Super 105* 5·3 g per denier.

To appreciate the significance of these advances it is necessary briefly to review the salient features of

the viscose process starting from α-cellulose pulp derived from wood chips and known as dissolving-pulp, as distinct from paper pulp. Fibre length in the dissolving pulp does not influence the fibre or yarn properties of the viscose rayon fibres regenerated from it, but the selection of timber and the method of pulping are important factors.

Figure 1. A steeping press showing cellulose pulp being immersed in caustic soda solution. (By courtesy of Courtaulds Ltd)

Wood pulp has to a certain extent replaced cotton linters for the production of cellulose acetate. Other sources are straw, but this is uneconomic, and bagasse, the residue from sugar cane; however the pulp producers have to compete for this with the sugar refineries who use it as fuel.

Up to a few years ago, sulphite pulp made from soft woods such as spruce was used almost exclusively for rayon production. There has been evolved recently a satisfactory pulp from hard woods, which are more plentiful than soft woods. It was generally believed until recently that no more sulphite plants would be built in North America, partly due to the sulphate process which is more flexible and permits of waste liquor recovery with consequent saving in fuel costs, and a diminution of river pollution. However, the development of the magnesia base process in which magnesia replaces lime in the calcium bisulphite process, and of the ammonia-base process, has given a new lease of life to the sulphite process since waste liquor is recovered, and sulphite plants are still being built in the U.S.A.

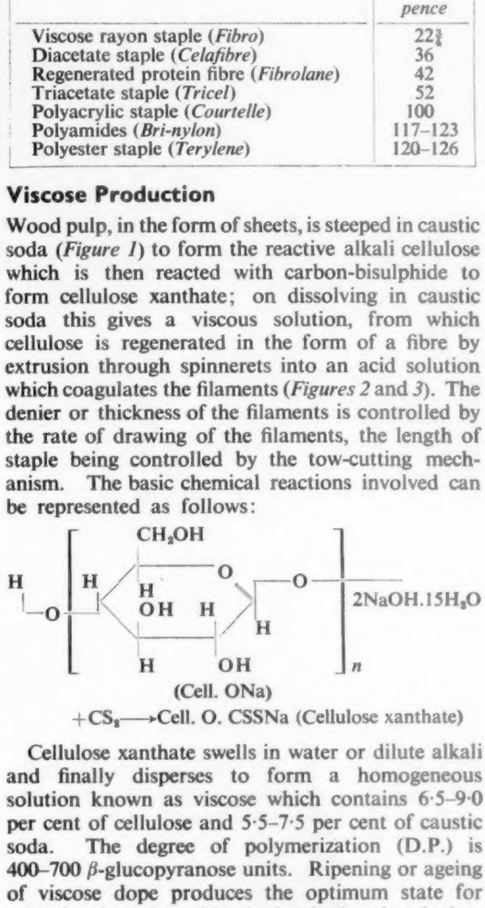
Although the viscose process was discovered as long ago as 1892 by Cross and Bevan, and was first operated commercially in 1905 by Courtaulds, it still provides by far the greatest percentage of the total production of man-made fibres, *viz.* 74 per cent; the remaining 26 per cent comprises 11 per cent acetylated cellulose and 15 per cent wholly synthetic fibres. The chemicals required are all cheap and in plentiful supply, namely cellulose (wood pulp), sulphuric acid, caustic soda, carbon disulphide and zinc sulphate. It is small wonder that viscose rayon staple is the lowest in price of all the man-made fibres and at the same time gives very good value for money. *Table 2* indicates current selling prices ruling in England.

Table 2

Fibre	*Price per lb in pence*
Viscose rayon staple (*Fibro*)	22¾
Diacetate staple (*Celafibre*)	36
Regenerated protein fibre (*Fibrolane*)	42
Triacetate staple (*Tricel*)	52
Polyacrylic staple (*Courtelle*)	100
Polyamides (*Bri-nylon*)	117–123
Polyester staple (*Terylene*)	120–126

Viscose Production

Wood pulp, in the form of sheets, is steeped in caustic soda (*Figure 1*) to form the reactive alkali cellulose which is then reacted with carbon-bisulphide to form cellulose xanthate; on dissolving in caustic soda this gives a viscous solution, from which cellulose is regenerated in the form of a fibre by extrusion through spinnerets into an acid solution which coagulates the filaments (*Figures 2* and *3*). The denier or thickness of the filaments is controlled by the rate of drawing of the filaments, the length of staple being controlled by the tow-cutting mechanism. The basic chemical reactions involved can be represented as follows:



(Cell. ONa)

$$+CS_2 \longrightarrow \text{Cell. O. CSSNa (Cellulose xanthate)}$$

Cellulose xanthate swells in water or dilute alkali and finally disperses to form a homogeneous solution known as viscose which contains 6·5–9·0 per cent of cellulose and 5·5–7·5 per cent of caustic soda. The degree of polymerization (D.P.) is 400–700 β-glucopyranose units. Ripening or ageing of viscose dope produces the optimum state for extrusion into the acid spinning bath, when hydrolysis occurs to regenerate cellulose in the form of a tow of filaments.

$$\text{Cell. O}-\text{CS}-\text{SNa} \xrightarrow{H_2O} \text{Cell. O}-\text{CS}-\text{SH} \rightarrow \text{Cell. OH} + CS_2$$

(Viscose)

Viscose may be coagulated in fibrous form and regenerated to cellulose by a variety of spinning bath compositions, but those commonly used

contain approximately 10 per cent sulphuric acid, 15–25 per cent sodium sulphate and 0·5–5 per cent zinc sulphate. Within a few seconds of the viscose dope emerging from the spinneret into the acid spinning bath, the following three processes occur, and determine the fine structure and characteristics of the filament or fibre: (*i*) the initial process of coagulation of a thin skin around a fluid core; (*ii*) the outward passage of water carrying with it some alkali and sodium thiocarbonates through the skin or membrane (by osmosis); (*iii*) the inward diffusion of spin bath electrolytes particularly bisulphate ions and zinc ions. Further molecular orientation can be imparted by subsequent stretching, *e.g.* in hot dilute acid to confer increased tenacity. The depth of the skin formed is a measure of the extent to which zinc ions have diffused into and reacted with the filament substance possibly to form cross-links of zinc-cellulose xanthate. Coagulation and decomposition of sodium cellulose xanthate are effected by the more highly mobile bisulphate ions.

The revolutionary improvements in viscose fibres and filaments and the production of new cellulosic fibres have been achieved by selection of wood pulp, by varying the conditions of formation of alkali cellulose and by varying the composition of the spinning bath. Thus a coagulant richer in zinc gives a fibre with a thicker and tougher skin which gives improved mechanical properties—increased tensile strength and greater breaking elongation. Combined with stretching through hot dilute acid to orient the fine molecular structure, the high zinc content bath has resulted in the production of an all-skin type of fibre with a smooth cross-section which, as a result of this homogeneity across the fibre thickness, is appreciably stronger than the original high tenacity viscose yarns. These developments are the basis of the production of *Tenasco Super 70* and *Super 105* and the viscose rayon staples *M55* and *M95*.

Coagulation by means of an ammonium sulphate bath results in filaments without skin. Measurements of density and interpretation of the results of x-ray diffraction indicate that the skin substance has about the same overall degree of crystallinity as the core, namely 40 per cent. The greater accessibility of the skin substance has been interpreted to mean that this cellulose contains a large number of small crystallites, whereas the core has fewer but larger ordered regions. The consequences of such a difference, taking into account the linear nature of the cellulose molecule, are far-reaching, permitting of greater orientation for a given stretch, reduced chain slippage, lower water swelling and increased flexibility.

A knowledge of the skin–core relationship and its methods of control has consequently led to a range of new regenerated cellulose fibres possessing a variety of characteristics which are predictable and quite different from those of the original viscose rayons. At the two extremes of this range are: (*i*) fibres comprising all-skin as M55 and M95 of smooth or bean-shaped cross sections, tough and resistant to abrasion either dry or wet, stronger than cotton when wet and much stronger when dry; and (*ii*) fibres comprising all-core, *i.e.* no skin, which are characterized by high strength and low extensibility when wet. Consequently these fibres give yarns and fabrics which are dimensionally stable (do not shrink or stretch) when washed.

High wet-modulus or 'polynasic' fibres, *i.e.* all-core fibres such as *Toramomen Z54*, *SM27*, *Fiber 500* and *Fiber 40* can be produced by various processes, *e.g.* by spinning into ammonium sulphate solution, or into acetic acid, sodium acetate and sodium sulphate, and stretching the fibres 50–100 per cent. A third method is a modified Lilienfeld process giving fibres of 7 g per denier and relatively low extensibility of 10 per cent either dry or wet. The starting point is an alkali cellulose of high D.P. and the xanthation indicated by the chemical formula above takes place in the absence of oxygen to give a highly viscous viscose which is extruded into 60–70 per cent sulphuric acid and highly-stretched. The filaments are allowed to relax in air before washing.

An ingenious method of producing curled or chemically crimped viscose staple fibres, is by extending the viscose to give an asymmetrical or

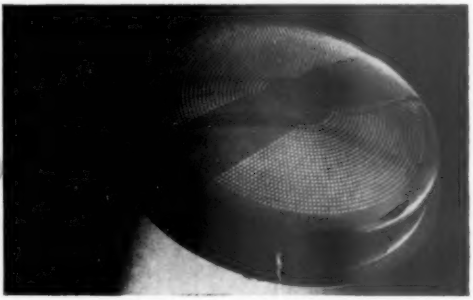


Figure 2. A spinning jet, with pin for comparison of size. (By courtesy of Courtaulds Ltd)

lop-sided filament resulting on coagulation in a thick skin on one side of the filament and a thin skin on the other. Since skin and core swell differently when wetted, the asymmetric fibres bend or kink. In this crimped Fibro, the curl is built into the

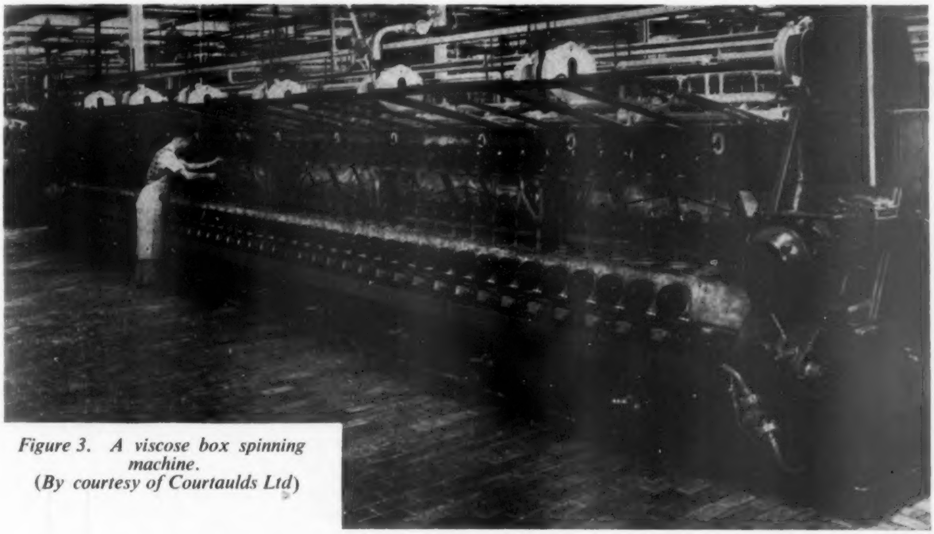


Figure 3. A viscose box spinning machine.
(By courtesy of Courtaulds Ltd)

structure of the fibre, so that even when it is pulled out during processing, it reappears as soon as the fibres, yarns or fabrics are wetted; this effect is noticeable in knitting yarns, or in the pile of tufted carpets produced from crimped Fibro.

'Slub' or 'thick and thin' filament yarns are produced by varying the rate of delivery of viscose dope by the pump to the spinneret. Slub yarns are used to confer surface interest to dress fabrics. Flat or ribbonlike filaments can be produced from slits instead of circular holes in the spinneret, and hollow-filament fibres can also be produced.

Other outstanding cellulosic filaments or fibres are produced by the incorporation of coloured or white or black pigments in the dope before extrusion into the coagulating bath. The pigments are critically selected for fine and regular particle size, and fastness to light, washing, dry-cleaning and other agencies such as industrial atmospheres. The 'spun-dyed' or *Duracol* fibres or filaments are consequently of value for clothing which has to be washed frequently (such as nurses' uniforms, or work clothes) or which will be exposed to bright sunlight. The coloured pigment is an integral part of the fibre and is dispersed throughout the fibre or filament. Recently it has been discovered that most of the dispersed pigments also protect the cellulosic fibres from photo-degradation and deterioration by industrial atmospheres. Comparative weathering trials conducted at Droylsden, Manchester during two years' exposure, demonstrated that heavy fabrics of 100 per cent *Fibro-Duracol* in fourteen different shades lost 25–45 per cent of their tensile strength, whereas 100 per cent cotton fabric of the same construction and dyed with non-tendering vat dyes lost 63–72 per cent of strength. Both fabrics initially possessed a breaking strength of 300 lbs, and after two years of weathering exposure the spun rayon fabrics had a strength of approximately 300 lbs, whereas the comparative vat dyed cotton fabrics had a strength of only 200 lbs. The results have been plotted in *Figure 4*. Pigmentation or coloration in the mass is the cheapest method of producing fast shades.

For further information on the fine structure of regenerated cellulosic fibres see references 1–10.

Merits of Viscose Rayon Staple and Continuous Filament Yarns

The comfort of garments made of viscose rayon and of diacetate fibres and yarns (*Celafibre* and *Dicel*) is mainly due to their water absorbency and softness. Diacetate has the added advantage of being inherently shrink-, crease- and mildew-proof but is weaker and not so resistant to abrasion or heat as standard viscose rayon. Some of the new cellulosic fibres described previously in this paper, however, do not shrink appreciably, but they are not yet available in large quantities, and will be slightly more expensive than standard viscose.

Meanwhile, standard Fibro, Strong Fibro (for finer counts of yarn), crimped Fibro and Fibro-Duracol are entirely satisfactory for woven or knitted fabrics if given chemical stabilized finishes such as urea-formaldehyde, melamine-formaldehyde or similar resins which confer crease recovery

properties as well as shrink resistance. Regenerated cellulose fibres with so many exposed hydroxyl groups in their molecular structure are specially reactive with certain chemicals such as formaldehyde to form stabilizing cross-links. Viscose rayon also has excellent dyeing and printing properties.

A combination of Viscose-Duracol filament, as weft across two-fold spun yarns of Fibro-Duracol woven on Jacquard looms, has been used to produce the *Duracour* range of upholstery, lampshade and travel bag fabrics which have been finished on one side with a synthetic latex. The high tenacity of Strong Fibro enables fine counts of yarns to be spun on the cotton system, suitable for weaving fine poplins and satins and sateens of attractive lustre for printed dress fabrics such as *Seriche*. The absorbency and purity of viscose rayon make it suitable for medical and surgical dressings.

Because viscose rayon can be supplied in continuous tow form, new methods of spinning yarns have been developed by stretching and breaking into short fibres which are then drawn and twisted in yarns—a procedure known as direct spinning. Another short cut in spinning procedure is by cutting the tow obliquely (by a helical cutter on a drum) and drawing the parallel fibres together into top form for spinning. Although one would expect such short cuts to lead to significant cuts in cost, these economies have not in fact been realized excepting with very fine counts of yarns.

Blends with Viscose Rayon Staple

Blending with cotton of Strong Fibro, standard Fibro or Fibro-Duracol to confer colour without further yarn or piece dyeing has been successful in household and apparel goods to confer long wearing life, appearance and comfort superior to those of the 100 per cent cotton or 100 per cent Fibro counterparts. A blend yarn or fabric of one third Fibro, two thirds cotton is of the same strength wet as dry, 50/50 blends are also of wide application.

The Fibro confers (*i*) a higher degree of absorbency, (*ii*) smoother and more regular yarns and fabrics, (*iii*) price stability, (*iv*) fast colour (in Duracol), (*v*) improved resistance to abrasion when dry, (*vi*) softer draping qualities, (*vii*) chemical affinity with less tendering on treatments with resins such as urea-formaldehyde (under acid conditions) to confer crease, shrink and stretch resistance, minimum-ironing and rapid-drying qualities, (*viii*) ease of washing due to the smoothness of the fibres.

That these improvements are achieved in practice have been proved and demonstrated by wear trials with nurses' uniforms, by men's knitted underwear trials and by overall or laboratory coat trials[11]. These have included trials with 186 uniforms worn at a hospital for three years, denim and drill overalls, jackets and trousers, and also knitted underwear. The average number of washes and wearings, before the blend underwear was worn-out was over 100 compared with 80 for 100 per cent cotton, and the average number of wearing periods before the appearance of the first hole was over 100 for the blend and only 69 for the pure cotton. The blends were markedly superior in their resistance to abrasion and to degradation by perspiration.

The Fibro–cotton blends have obvious application to towellings, because of absorbency and resistance to abrasion. A comparison of 100 per cent cotton and a one third Fibro and two thirds cotton pile on a cotton ground was made in terry towels. After five years' use the pure cotton terry pile had worn away almost completely, whereas the Fibro–cotton blend terry pile still possessed a reasonable cover, thicker or more dense at the ends of the towel than near the centre. Analysis of the blend pile disclosed that near the ends of the towel, *i.e.* the least worn portions, the blend was 33 per cent Fibro, 67 per cent cotton, whilst in the worn portions near the centre of the towel it was 65 per cent Fibro, 35 per cent cotton, thus clearly demonstrating the more durable nature of Fibro compared with cotton under repeated washing and rubbing conditions, the cotton fibres having been worn away leaving a predominance of viscose rayon staple.

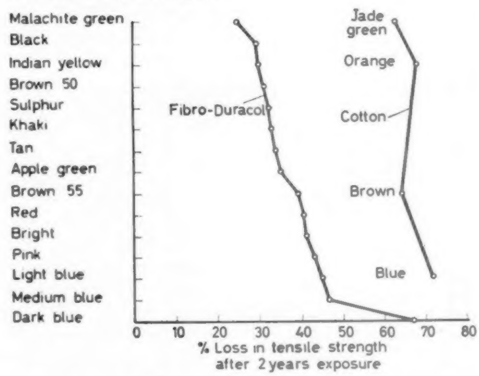


Figure 4. Weathering of Fibro-Duracol and vat-dyed cotton

There are many advantages in blending viscose rayon staple with other fibres. These include

(*i*) Wool; the blend has less tendency to shrink or felt than wool, gives stronger fabrics of higher tear strength, more resistance to abrasion, significantly lower costs and good cross-dyeing effects.

(*ii*) The so-called synthetic fibres, to give low priced trousering and costume cloth, resistant to abrasion, which can be chemically finished to confer crease recovery and shape stability. The viscose rayon staple confers absorbency and washability and counteracts the development of static electricity; it possesses many advantages over cotton for blending with polyamides (nylon), polyesters (Terylene) or polyacrylates (Courtelle)—mainly because it is a smoother and more regular fibre (in length and diameter) which results in a less fibrous surface, easier to iron and less liable to pill or to become fibrillated or fuzzy than the corresponding cotton blends. Dr R. W. Peterson of Du Pont in his lecture to the Textile Institute Annual Conference in 1958 stressed the advantages of viscose staple over cotton for blending with *Dacron* and *Orlon*, and quoted experimental results as supporting evidence.

Blends of 70 per cent viscose staple with 30 per cent of polyvinylchloride fibre (*Rhovyl*) in knitted fabrics, afterwards shrunk and raised, are used for suede or buckskin jackets (less than half the price of leather) which can be washed or sponged clean with soap and lukewarm water, a procedure which is anathema for suede leather.

(*iii*) Cellulose triacetate (*Tricel*) for knitted underwear and knitted or woven outer wear, and, because of the heat-setting properties of triacetate, for pleated dresses and skirts.

Linings and interlinings are usually woven from viscose rayon filament because of its smooth and non-snagging surface. Coarse denier viscose rayon staple spun on flax spinning machinery and finished with crease-resistant resins is used for tie-interlinings and for tailors' trimmings because of firmness of handle combined with resilience.

Bonded fibre fabrics or non-woven tissues produced by bonding webs of viscose staple fibres (or blends of them with nylon and wool) with rubber latex or with *Hycar* (polyacrylonitrilebutadiene), are also being used in increasing quantities for tailors' interlinings and for under skirts. They are suitable for use in washable suits, since they dry rapidly.

Conclusion

The information and evidence indicates that viscose rayon continuous filament yarns, and staple fibre, together with other newer cellulosic fibres—markedly different in characteristics from the original regenerated cellulosics—are fulfilling an important role in apparel textile and will continue to do so because of their low price, availability in many different forms and versatility. It is foreseen that the cellulosics will become increasingly important in blend with either the newer synthetic poly fibres, and/or the natural fibres.

To give satisfaction to the consumer it is necessary to have tests of quality and performance together with appropriate labelling and, of course, consumer education on practical qualities such as the fabric's behaviour when washed or dry cleaned.

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Appendix

The use of various fibres in the clothing industry in the United Kingdom during 1958 is summarized in *Table 3*. From *Table 4* the vast potentialities for textiles in under-developed countries can be seen.

Table 3

Fibre	Woven goods %	Warp-knitted goods %	Stockings %
Cotton	45	4	3
Wool	24	2	1
Spun viscose and acetate	13	—	—
Continuous filament viscose and acetate	13	30	2
Continuous filament synthetics	5	64	94

U.K. per capita fibre consumption

Fibre	1938		1955	
	lbs	%	lbs	%
Cotton	16·9	65	14·5	52
Wool	7·0	27	5·9	21
Rayon	2·0	8	6·4	23
Synthetics	—	—	1·3	4
Total	25·9	100	28·1	100

Table 4. World per capita fibre consumption

Fibre	1938		1955	
	lbs	%	lbs	%
Cotton	6·4	78	6·9	69
Wool	0·9	11	1·0	10
Rayon	0·9	11	1·9	19
Synthetics	—	—	0·2	2
Total	8·2	100	10·0	100

BRITTLE LACQUERS

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The brittle lacquer technique is introduced by reference to everyday examples of the random cracking of surface coatings. Factors influencing the behaviour and development of lacquers are briefly considered and attempts to overcome difficulties inherent in the utilization of organic substances described. The application and calibration of coatings is described and reasons for the recent revival of the technique are commented upon. Some illustrative problems are given.

MOST people, at one time or another, have observed the random hairline cracks on the glazed surface of bathroom tiles, the cracking of the vitreous enamel coating near the rings on the supporting surfaces of some domestic gas cookers, on the external surface or anodized aluminium kettles, and on numerous other surface layers applied specifically for the purpose of affording protection against corrosion or for enhancing the appearance of an article. These everyday examples, whilst normally undesirable, illustrate one of the many useful characteristics of certain types of surface layers.

The layers have cracked simply because relative movement has taken place between the surface finish and the article itself. In the case of the gas cooker, for example, heat causes the supporting metalwork near the gas ring to expand and since the vitreous enamel coating has a different coefficient of thermal expansion from that of the underlying metal it is unable to follow this expansion and also, being firmly attached to the metal, it cracks.

Usually in such instances where the expansion due to rise in temperature, or extension due to the application of loads, has occurred in a preferential manner, the cracks form a distinctive pattern and arrange themselves in a family of curves in sympathy with the local distortions of the article upon which they are coated. This phenomenon is exploited in the measurement of strains in prototypes and models of engineering components and structures, namely the science of *experimental stress analysis*, under the heading of the brittle lacquer technique. For convenience and ease of handling brittle coatings are invariably applied in the form of a clear varnish or lacquer to a thickness of between 0·002 in. and 0·008 in. and are generally known as brittle lacquers to distinguish them from brittle coatings a term often used to describe any type of brittle surface layer.

Examples of the unpredictable fractures of surface coatings have been mentioned, but however, since the class of coatings we are considering can also be made to fracture under known loading conditions it is possible to define broadly such a material as a specially prepared lacquer coating which, when applied to an elastic sublayer and allowed to dry to a suitable extent will crack upon the application of a certain level of strain to the sublayer. This strain, the ratio of the local extension of the part to the unstrained base length over which the extension was measured and known as the strain sensitivity, is the maximum principal tensile strain the coating can withstand; the exact magnitude of the strain depends on the type of coating employed and its history, comprising the drying time and temperature, the thickness of the coating, and the method of application, whether by brush or by spray gun.

The laws which govern failure of the coating depend, as one might expect, upon Young's modulus, Poisson's ratio, and the ultimate tensile stress characteristics of the lacquer; in practice none of these properties are very easy to determine. Furthermore, lacquers and varnishes are not brittle but elastic and unlike vitreous enamels and similar coatings they exhibit an additional and most unwelcome property, that of creep under load.

The sublayer, a term borrowed from paint technology, embraces any material, thick or thin, metal, plastic, glass, or wood, and so on, upon which the lacquer is coated. The majority of lacquers adhere very strongly to most materials up to quite large deformations and, owing to the volatile solvents they contain, are usually applied with a spray gun.

Lacquer Development

The fracture and spalling of mill scale, the inextensible iron-oxide layer which forms on the surface of hot-rolled steel members, is known to have been associated many years ago with the deformation of the steel carrying the scale[1].

One of the earliest references to what has now become known as the brittle lacquer technique may be found in a treatise by CLARKE[2] on the construction of the Britannia and Conway bridges, dated 1850, in which he describes the flaking of paint away from the surface of a structural model and comments upon the occurrence as a possible basis for measuring large strains. There is, however, some reason to believe that the brittle lacquer method, as such, was first devised by Dietrich in Germany during 1924, being applied in a qualitative manner by the Maybach Company to the study of stress concentrations and principal stress orientation in reciprocating engine components.

Since that time many substances other than ordinary paint have been used as brittle coatings including whitewash[3] and portland cement[4]; in 1925 the first recorded use was made of resinous substances, shellac dissolved in alcohol[5] and colophony dissolved in benzol. Numerous and quite successful attempts[6,7], have been made to apply Plumber's resin in powdered form to complex components heated by means of a blowlamp to a temperature high enough to melt the powder into a continuous surface film.

There are today two very well known lacquers commercially available, *Stresscoat*[8] an American product and *Strainlac* which exhibits somewhat similar characteristics to Stresscoat but which is manufactured in this country. Both these lacquers utilize carbon disulphide as the principal solvent; this material being extremely toxic and inflammable, presents an acute hazard to the health and safety

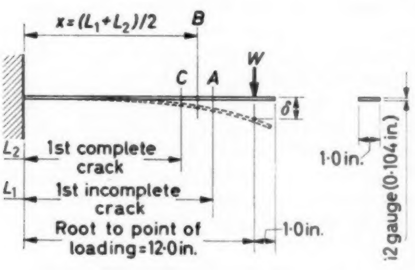

Figure 1. Dimensions of early type of light alloy cantilever calibration beam

of the operator and because of this restrictive precautions have to be observed. Owing to the high vapour pressure of the solvent great care has to be taken in order to maintain concentrations below the safe threshold limit in locations visited by general personnel.

Strainlac the British carbon disulphide lacquer has within recent years cost about £25 per gallon, a not inconsiderable sum especially when compared with the cost of ordinary paints at 50/- to 60/- per gallon.

Figure 2. Typical formation of crack pattern in cantilever calibration beam

Strain sensitivities as high as 0·0003 in./inch are obtainable with Stresscoat and Strainlac corresponding to stresses of about 3000 lb/in.^{2} in light alloy and about 9000 lb/in.^{2} in mild steel, although quantitative analysis becomes somewhat doubtful at this extreme sensitivity. These types of lacquers react to changes in temperature to the extent that a 4 per cent change in temperature will alter the strain sensitivity of Stresscoat or Strainlac from a good working value of 0·0007 in./inch to a useless crazed condition consisting of a pattern with a completely random orientation of the cracks. Nevertheless, on the credit side it is safe to say that both lacquers, perhaps more especially Stresscoat, have been widely used and good results have been obtained by several investigators.

There are six or seven other brittle lacquers commercially available which do not contain carbon disulphide; these are reasonably priced but have, more or less, with only two or three exceptions, a rather modest performance.

All the organic lacquers may be dried under natural conditions or they may be forced dried at elevated temperatures, either to accelerate drying or to

improve an otherwise moderate strain sensitivity, depending on whether the component in question can be accommodated within a drying cabinet. In general the drying cabinet should contain heaters of sufficient power to raise the ambient temperature to at least 100°F.

Most, if not all, organic lacquers contain a natural or synthetic resin, a solvent and a plasticizer. The plasticizer is in effect a solvent which never evaporates and is used to control the strain sensitivity and general performance of the resin–solvent mix; the plasticizer also influences the drying time of a lacquer. For technical reasons there are usually a number of solvents incorporated in a finalized lacquer to obtain what is termed the correct solvent balance.

Many lacquers available today can be criticized on the grounds of high cost, inflammability and toxicity, unsatisfactory strain sensitivity when dried under ambient conditions, and their dependence on temperature or upon the relative humidity. It is not difficult to appreciate the reason for the tendency of investigators to diverge from the use of long established organic brittle materials especially the carbon disulphide lacquers and hence the restrictions imposed by their use; the tendency is explained by an interesting contribution to the lacquer technique by HICKSON and STRAIN[9] outlined in their paper to the Institute of Physics Stress Analysis Group Annual Conference in 1954. The paper deals

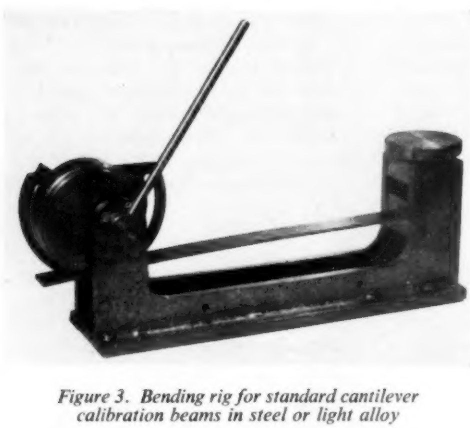

Figure 3. Bending rig for standard cantilever calibration beams in steel or light alloy

with the early stages in the development of water soluble glasses, in the first instance a borax–boric acid glass and subsequently other water soluble glasses including lithium tetraborate which tends to form a supersaturated solution, eventually drying to an amorphous glass. Later experiments were apparently concerned with the investigation and uses of lithium hydroxide.

The unavoidable and unfortunate dependence of the water soluble glasses upon relative humidity immediately creates difficulties in application. A crazed coating is in evidence below 40 per cent R.H., and a soft unusable coating above 50 per cent R.H. a state of affairs requiring careful control over the ambient atmospheric conditions and other specialities of technique.

A report on an investigation of vitreous enamels undertaken with the object of extending the utility of existing brittle coatings is given by SINGDALE[10]. Enamels, known commercially as *Stresscoat All-Temp*, have been produced with a strain sensitivity range from 0·00013 in./inch to 0·0017 in./inch using steel as the sublayer. These coatings are sprayed onto the sublayer in the form of a dry powder thoroughly mixed with distilled water; the composition is then dried within the range 150°F to 180°F until all the moisture is driven off, after which the part is fired at 1000°F for twelve minutes. Extensive crack patterns have been obtained in specimens tested at operating temperatures of up to 750°F.

BOITEN[11] and his colleagues neatly by-passed many of the difficulties enumerated previously with the development of a flame spraying method. Spraying is carried out with an ordinary gas blowpipe; the air supply to the blowpipe is passed through a coffee mill in which the specially prepared granules of Plumber's resin are reduced to powder, diffused into the air stream and are thence carried *via* the flame onto the component. It is claimed that sprayed specimens become only moderately heated and after cooling down can be loaded to give crack patterns having a strain sensitivity of between 0·0003 in./inch to 0·0005 in./inch.

Paint manufacturers are not in general anxious to undertake the development of brittle lacquers on economic grounds, an attitude arising simply from the fact that development work places a heavy call upon finance, time and labour, and that the market demand for such lacquers is small and hence sales are measured in pints rather than in thousands of gallons. One or two manufacturers no doubt market brittle lacquers for purposes of prestige while others have developed them from a by-product of existing research.

The illustrations used here refer to a lacquer developed within an Aircraft Company with some assistance from the Chemistry Department of that company. From this work, carried out at intervals over a period of four years it was concluded that the development of a first class organic lacquer, of

reasonable price, having a useful and controllable strain sensitivity, being essentially non-toxic and perhaps non-inflammable, presents a formidable problem even to a trained chemist accustomed to this type of work. The task is not so simple or so easy as one might imagine which may well explain the gradual trend toward completely new materials and methods, and of overcoming the associated restrictive procedures.

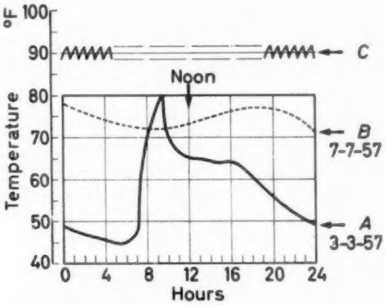

Figure 4. Typical relationship between temperature and time for, (a) structural test laboratory during March 1957 and (b) for July 1957, (c) temperature cycle in thermostatically controlled drying cabinet

Application of Lacquers

Brittle lacquer provides an overall and continuous picture of the state of strain at the surface of the component in question and is analogous to the covering of the component with a multitude of strain gauges of very short gauge length, from approximately 0·10 in. to 0·010 in. or less. Strain, and hence stress levels at stress concentrations in complex machines parts can frequently only be estimated experimentally by means of lacquers, since the critical regions are in character often too small or awkwardly shaped to allow the successful application of electric resistance strain gauges and extensometers. In many cases the strain gradient is quite steep and because mechanical and electrical strain gauges integrate the total strain over their gauge length to give an average strain, the order of accuracy obtainable using such instruments under these conditions may not be very great, and in fact, not so high as that of the results achieved by using brittle lacquers.

Experience has shown that results of the order of 5 per cent to 10 per cent accuracy can be expected at stress concentrations and in regions adjacent to free edges or boundaries of components where the strain is uniaxial, or from 10 per cent to 20 per cent away from these regions where different conditions may prevail, for example, in a field of biaxial strain.

In many components a state of biaxial strain does exist; the strain sensitivity of lacquers is affected by the cross strain, but provided that the cross strain does not exceed about one quarter of the maximum principal strain orders of accuracy from $\pm$ 10 per cent to $\pm$ 20 per cent can be realized. This is a generalization and the actual accuracy that can be achieved depends on many factors, one of them being the skill of the operator.

Now these values of accuracy, $\pm$ 10 per cent to $\pm$ 20 per cent may appear to be errors large enough to detract seriously from the usefulness of the method but it must be remembered that the stress levels under investigation may not be known in any event to within 50 per cent of the actual value and that they invariably occur in regions of such size and geometry as to prohibit most, if not all, other methods of direct stress measurements.

In order to obtain these high accuracies however, very careful attention has to be paid to the various aspects of the technique at all stages including the preparation of the lacquer, the cleaning of the surfaces to be sprayed, the application and calibration of the lacquer, and so on.

American studies of Stresscoat suggest that there are 34 variables which can influence the final behaviour of the coating. The main group headings of these variables comprise: (1) the liquid state of the lacquer; (2) adjustments of the spraying unit; (3) the application of the coating; (4) heat treatment (forced drying); (5) testing conditions; (6) stress conditions; and (7) other factors.

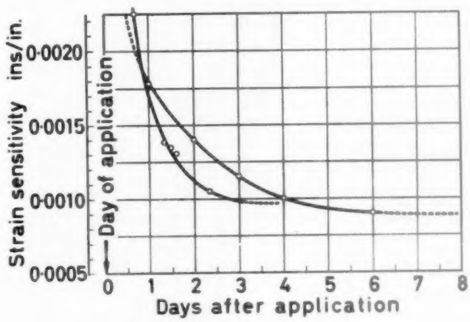

Figure 5. Improvement with time of strain sensitivity for two fast drying brittle lacquers after day of application under conditions defined by curve B in figure. Each plot represents average of tests on four individual cantilever calibration beams

The Calibration of Lacquers

When coating a component lacquer is simultaneously sprayed onto a number of calibration beams, eight is a convenient number, which are strained in a simple bending rig at the same time as the component itself is loaded. This procedure helps to ensure that the lacquer on the component and on the calibration beams experiences the same drying time and finally obtains the same strain sensitivity after a given time period. It is also most important to manufacture the calibration beams in the same type of material as the component, primarily to match coefficients of thermal expansion, but also to avoid small discrepancies in behaviour which can be observed when different types of materials are coated with one and the same lacquer.

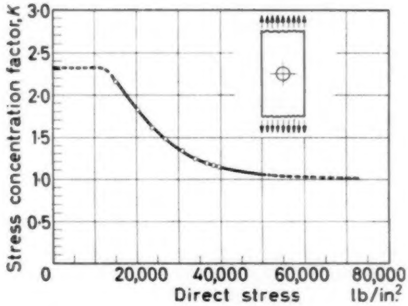

Figure 6. Decrease of elastic stress concentration factor with increase in stresses for D.T.D. 610b. plate specimen with central hole

Throughout the drying life of the lacquer, the component and the calibration beams are kept in close proximity to minimize the effect of temperature differentials between the two. This precaution has to be observed because, as has already been mentioned, the characteristics of organic lacquers are much influenced by the ambient temperature and to a lesser extent by the humidity of the atmosphere.

Figure 1 shows the position of the first incomplete and the first complete cracks in the lacquer on a standard calibration beam. Dimension x, which represents the mean of the two distances A and C, measured from the root of the cantilever, can be taken as an indication of the strain sensitivity of the lacquer. Some workers choose point A from which to determine the strain sensitivity but since with a number of lacquers points A and C are very nearly coincident this is of little consequence. Note that we are interested in the point where cracks start, or to put it another way, in crack initiation and crack progression, rather than in the number of cracks per inch, although the latter parameter may be used to obtain a qualitative idea of the magnitude of a strain gradient at various regions in a complete crack pattern. The deflection δ, is quite arbitrary and is adjusted to suit the range of strain sensitivities and materials being dealt with at the particular time.

Figure 2 shows the typical formation of a crack pattern on a cantilever calibration beam and *Figure 3* the essential of a cam operated beam bending rig with a steel beam in position partially deflected.

Since the strain sensitivity of lacquers depends to an appreciable extent on their temperature/time history one can readily appreciate that the procedure of drying out a lacquer quickly and of predicting when a component can be tested, that is, when the strain sensitivity has reached a satisfactory value, is frequently very difficult under the conditions of routine structural testing. Curves A and B, in *Figure 4* represent the ambient temperature in March and July respectively in a typical structural test laboratory. The sharp increase in temperature and peak in curve A is due to heaters in the roof of the laboratory being switched on prior to the staff commencing work. Curve C represents the type of conditions existing in a thermostatically controlled drying cabinet 7 ft 6 in. wide by 3 ft 3 in. deep by 4 ft 6 in. high, this being large enough to house quite substantial components. Not only does the higher temperature enable the lacquer to be dried more readily but also the restricted range of temperature, virtually a constant, facilitates prediction of the time at which a satisfactory strain sensitivity will be achieved. *Figure 5* shows the improvement with time of the strain sensitivity of two fast drying lacquers under the conditions defined by curve B in the last figure.

The Revival of Brittle Lacquers

We might now briefly consider why brittle lacquers have gradually become more and more a centre of attention during the last ten or fifteen years. There appears to be a number of reasons.

The last decade has seen a number of unfortunate structural failures from fatigue; failures by this cause, particularly in helicopters and aircraft, are usually quite dramatic—a rotor, wing, or tailplane detaches from the main fuselage and the aircraft itself becomes a total wreck. Such a disaster makes front page news and in consequence one does not hear or read about the failure of a locomotive connecting rod for example, an incident which could

have serious consequences; it must be appreciated that fatigue failures of one kind or another occur in most fields of engineering where appreciably large dynamic loads are present.

In fact numerous service failures of all types may be attributed to fatigue although the latter may have been the indirect consequence of an unsuitable choice of material for the design or a poor design in itself.

Fatigue failures invariably originate at stress concentrations or discontinuities at the surface of a component, a state of affairs which is indeed fortuitous so far as the stress analyst is concerned. To obtain some knowledge of the level to which structures can be loaded dynamically it is most useful to have to hand information on the magnitude of the stress concentrations in the individual parts which go to make up the structure, since from such information it is frequently possible to derive an estimate of the fatigue life under given loading conditions. The major usefulness of the brittle lacquer method would therefore appear to lie in its application to static tests on components whose life is ultimately governed by dynamic rather than by static loading, since in the latter case yielding, sometimes termed plastic unloading, in ductile materials, reduces the elastic stress concentration factor to an effectively much lower value as loading proceeds, eventually to an asymptotic value of 1·0 at the ultimate stress.

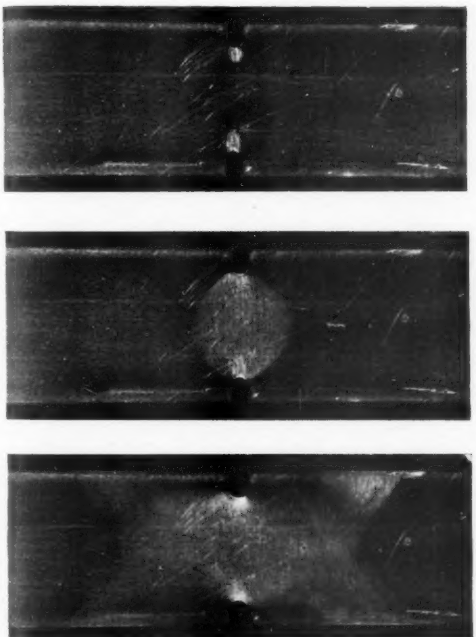

Figure 7. The outline formed by the extremities of the cracks, an isoentatic line, is clearly discernible at three stages of loading. Specimen in Nimonic 75, 1·50 in. wide by 20 gauge (0·036 in.) thick

So far as analysis is concerned it is most convenient to apply the lacquer technique to cases in which elastic deformation only takes place throughout the entire component; analysis can be undertaken in the plastic range but this adds considerable complication to the technique. The plastic unloading effect is clearly demonstrated in *Figure 6*, obtained from tests using a special photoelastic method employing birefringent plastic cemented to the metal test specimen itself.

Illustrative Problems

Some idea of the way in which a brittle lacquer crack pattern develops is given by *Figure 7* which illustrates three stages in the tensile loading of a specimen in *Nimonic 75*, a heat resistant material, 1·50 in. wide by 20 gauge (0·036 in.) thick. The outline formed by the extremities of the cracks, an isoentatic line, *i.e.* a line of equal stretch, forms the locus of points of equal principal strain; the line thus represents a given and constant strain value. The crack lines themselves are termed isostatic lines. From the orientation, direction, and curvature of the isostatics it is possible, using rules based on the Lamé-Maxwell equations and principles advanced by Kayser and Herzog, to deduce the state of stress existing in a region covered by a given crack pattern while measurements of crack progression with respect to the external applied load provide information on the magnitude of stress.

The method of using brittle lacquers to determine the magnitude of a stress concentration is best illustrated by the simple example shown in *Figure 8*. The problem is to find the value of the stress concentration at the edge of the central hole and the stress distribution across the half width of the 4·0 in. wide thin plate loaded under uniform tension.

The method of tackling the problem which was originally treated as an exercise during the development of simple plastic models, prior to the commencement of tests on plastic models of complicated structural joints, was as follows.

A model of the plate was manufactured in *Perspex*, 3/16 in. thick, to the full scale dimensions given and

suitably reinforced at each end to take single pin pick-ups. The plate, together with eight cantilever beams, also in Perspex, was sprayed and allowed to dry until tests on two of the calibration beams confirmed that a satisfactory strain sensitivity,

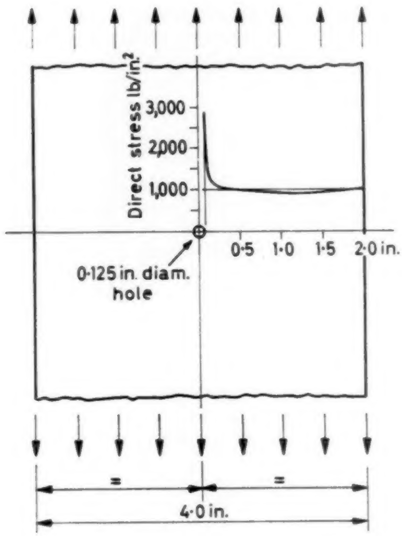

Figure 8. Perspex strip, 4·0 in. wide by 3/16 in. thick containing ⅛ in. diameter central hole subjected to uniform tension

0·0012 in./inch had been reached by the lacquer. Upon assembly and careful alignment in a test machine load was applied and a note was made of the progression of the cracks from the edge of the hole with respect to the external load applied at the time the measurement was taken.

A table was then prepared with three main columns, the headings of which were:—

Applied load. W. lb.	*The distance of the crack(s) from the edge of the hole. x in.*	*The stress at a given distance from the edge of the hole f. lb./in.^{2}*

The last column was computed from the knowledge of the strain sensitivity of the lacquer determined from the calibration beams, the dimensions of the specimen, and a law which states that the stress level at any given point is directly proportional to the strain sensitivity and inversely proportional to the applied load. The strain sensitivity of the lacquer was checked by obtaining a crack pattern across the unperforated width of the plate at a section far removed from the hole and noting at what load this took place. The external applied load divided by the cross-sectional area of the plate then represented the stress, and hence the strain, at which the lacquer cracked under reasonably uniform conditions of stress. After the brittle lacquer tests had been completed the strain levels across the section of the plate containing the hole were checked with a C.E.J. miniature extensometer having a gauge length of 0·10 in.

Figure 9 which shows the results of these tests, also demonstrates a typical case in which brittle lacquer and extensometry overlap. In the vicinity of the hole the integrating effect of the gauge length of the extensometer, which approaches the dimension of the discontinuity itself, precludes any attempts to measure the strain gradient with pretence at accuracy and the lacquer technique therefore comes into its own field.

When $x=0·50$ in. the predominating influence of the hole has died away and the extensometer can be used with confidence. Brittle lacquer analysis in this region, from about $x=0·50$ in. to the edge of the plate, $x=2·0$ in., is not so convenient however,

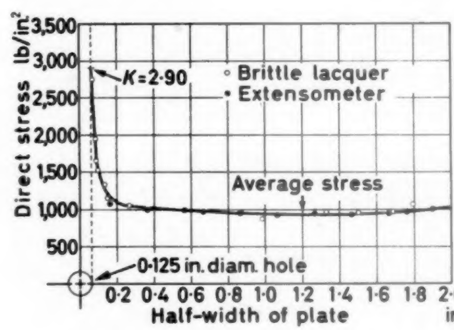

Figure 9. Comparison of extensometer and brittle lacquer results obtained from Perspex strip shown in Figure 8

since the rate of crack propagation becomes very rapid for small changes in the applied load, but despite this fact fair accuracy and agreement is achieved. The geometric stress concentration factor is 2·90 and a value very close to this was arrived at by plotting that part of the stress distribution curve adjacent to the hole against the plate dimension to

an expanded scale. *Figures 10* and *11* give a further self-explanatory example of the brittle lacquer technique.

Only a few of the varied and wide aspects of brittle lacquers and attempts by investigators to circumnavigate the problems which beset the use of the method have been touched upon.

There are already indications that the increasing demand for a satisfactory brittle lacquer, resulting from a more widespread appreciation of the potentialities of the method, is given an impetus to research which, it is hoped, will yield more suitable lacquers and at the same time provide a more comprehensive knowledge of the numerous parameters which affect their performance. The task is clearly of considerable magnitude and complexity generally beyond the scope and favour of industrial organizations not already equipped for such work. For this reason extensive investigations are most likely to be undertaken within a research organization, unless, as an alternative, research sponsored by industry generally can be carried out by a specific company.

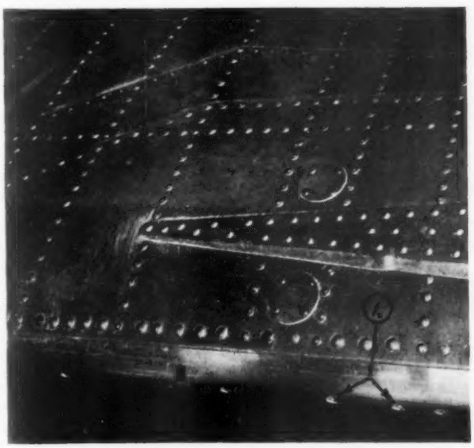

Figure 10. Brittle lacquer crack pattern showing load concentration near tip of strap joint located at root of helicopter rotor blade. During subsequent fatigue tests failure took place in the region indicated in Figure 11

In whatever way the problem is approached it is certain that research in this field will eventually pay handsome dividends in terms of improved practical design, particularly detail design, and should strengthen the arm of experimental stress analysis with which the lacquer technique has for so many years existed on a somewhat tentative basis. Surely

Figure 11. Fatigue cracks (shown arrowed) in skin of helicopter rotor blade in way of first rivet in strap joint

the technique, one of the most fascinating and useful branches of stress-analysis ever devised, is worthy of much more attention in this country than it has hitherto been given.

The author wishes to thank Fairey Aviation Limited, Hayes, Middlesex, where the investigations were undertaken, for kind permission to publish this paper, including the illustrations, and to acknowledge prior publication of the data in 'Aircraft Engineering', April, May, June, 1958.

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ROCKET PROPELLENTS

Part I. Liquid Propellents

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Rocket propulsion first attracted universal attention in the Second World War and since then has undergone considerable development because the use of rockets has been extended in the military field and for scientific and exploration purposes. Dr Parker discusses the selection of liquid propellents and the properties of some of the more interesting ones. In another article to be published later he will consider recent progress in solid propellents

ALTHOUGH the first military use of rockets has been attributed to the Chinese in the thirteenth century, the early history of the subject is obscure and does not contribute anything to present day technology. Early in this century a few pioneers began experiments in Russia, Germany and America but interest in their work even for military applications was not great and rockets played no significant role in the first World War. It was not until World War II that rockets became established in the military field and development of various kinds of rocket weapons was greatly accelerated. The most spectacular of these weapons was undoubtedly the large liquid fuelled German V2 rocket which demonstrated the great potentialities of this form of propulsion and was the forerunner of the ballistic missile of today.

Immediately after the war the Americans employed the surplus German V2 rockets for exploration of the upper atmosphere and later built special rockets such as the Aerobee and the Viking for this purpose. These developments were paralleled in Russia and later in Britain and France, where the Skylark and the Veronique respectively were designed and used to make measurements in the upper atmosphere during the International Geophysical year. In 1957 Russia launched the first instrumented earth satellite, Sputnik I, and since then other satellites have been placed in orbits round the earth by Russia and America. Towards the end of last year the Russians obtained excellent pictures of the moon and claimed that one of their rockets reached the moon's surface.

Thus, astonishing progress has been made in the last twenty years, using chemical rockets which burn liquid or solid fuels. These fuels are more correctly called propellents because chemical oxidizers are involved as well as substances which are commonly known as fuels, such as hydrocarbons. In 'liquid' rockets, propellents like liquid oxygen and kerosene are stored separately in tanks and pumped into the combustion chamber, while in 'solid' rockets a propellent such as cordite is ready filled in the combustion chamber. These two different forms of the rocket motor are illustrated in *Figure 1*.

Considerable research and development has been undertaken to improve the performance and handling of propellents and to find new and more powerful ones. Already rockets for scientific uses and exploration are beginning to make greater demands on propellents than the military rockets from which they are usually developed, and are beginning to indicate a need for engines with a higher performance than that theoretically available from the chemical rocket. The next step will most probably be an engine with a nuclear heat source coupled with a working fluid such as liquid hydrogen.

The Chemical Rocket

The principle of this type of engine depends upon converting part of the chemical energy of the propellents into kinetic energy. In the combustion chamber the propellents first undergo chemical change to produce hot gases at high pressure and these gases expand through a shaped nozzle to form a high velocity jet. In this way the random kinetic energy of the gases is converted into directed energy in the jet. The thrust which is developed is the sum of the pressure forces acting on the rocket and the change in momentum of the jet gases. Since these gases originate entirely from the propellents, the rocket is independent of the oxygen in the atmosphere and can operate in a vacuum or in the tenuous atmosphere of outer space.

Although the principle is the same, the technologies associated with liquid and solid propellent rockets are very different and it is convenient to consider each type separately. There is now immense rivalry between groups developing the two types because their fields of application overlap. This point will be considered again in Part II. The applications of liquid propellents lies principally though not exclusively in the long range rockets used for ballistic missiles and the launching of satellites.

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Selection of Chemicals for Use as Propellents

The choice of chemicals is governed partly by performance as assessed by the specific impulse, I, which is the ratio of thrust to the rate of propellent consumption, and partly by a variety of factors including physical and chemical properties such as boiling point, freezing point, stability, ease of handling, safety, availability, cost, *etc*. For height or range with large multistage rockets, specific impulse becomes of relatively greater importance and it is instructive to look at the expression linking I with the temperature, pressure, *etc*., in the combustion chamber.

Assuming isentropic expansion in the nozzle and frozen equilibrium in the jet gases

$$I = \sqrt{\left(\left[\frac{2}{g^2} \cdot \frac{\gamma}{\gamma-1} \cdot \frac{RT_c}{\overline{M}}\right]\left[1-\left(\frac{P_e}{P_c}\right)^{(\gamma-1)/\gamma}\right]\right)}$$

where T_c is the combustion temperature, P_c the combustion pressure, P_e the gas pressure at end of the nozzle, $\overline{M}$ the mean molecular weight of the combustion gases, R the gas constant, γ the ratio of mean specific heats and g the gravitational acceleration. The term

$$\left[1-\left(\frac{P_e}{P_c}\right)^{(\gamma-1)/\gamma}\right]$$

may be regarded as an efficiency term which gives the fraction of the available energy which is converted into kinetic energy in the jet. It is little affected by the nature of the propellents provided the products are gaseous but depends upon the ratio of (P_e/P_c) which is determined by the combustion chamber design. The advantage gained by increasing the combustion chamber pressure begins to diminish at higher pressure because of the increase in weight of the propellent pumps and other components. For liquid motors the working pressures were formerly about 300 lb/in.^{2} but with improved design and fabricature in recent years it has been possible to increase the chamber pressure to 600 lb/in.^{2} or even more.

The nature of the propellent influences the specific impulse through the factor

$$\left[\frac{2}{g^2} \cdot \frac{\gamma}{\gamma-1} \cdot \frac{RT_c}{\overline{M}}\right]^{\frac{1}{2}}$$

and a high thrust is largely determined by $\sqrt{(T_c/\overline{M})}$ or in other words by a high combustion temperature coupled with a low mean molecular weight.

The importance of the molecular weight as well as the temperature is illustrated in *Figure 2* where the specific impulse for the hydrogen–oxygen system is plotted against the mixture ratio. The maximum value of I is seen to occur with a fuel rich mixture while the maximum temperature occurs near to the stoichiometric mixture.

Liquid Propellents

In 'liquid' rockets it is possible to use a single substance or monopropellent, *e.g.* concentrated hydrogen peroxide (H.T.P.), ethyl nitrate or nitromethane, *etc*., which decomposes exothermally. Such a system is very simple but the performance is not as good as that obtainable from the reaction between an oxidizer and a fuel in a bipropellent system. The latter is always used now for the main propulsion of a rocket vehicle although monopropellents, especially H.T.P., are still used for auxiliary power units *e.g.* turbines to drive fuel pumps.

On a thermochemical basis the only oxidizers worth considering are oxygen and fluorine, together with certain compounds which act as carriers for these elements, *e.g.* H_2O_2, ClF_3 *etc*. The choice of fuels is much wider but those giving the best performance with either oxygen or fluorine are hydrogen and compounds of hydrogen with some of the lighter elements, *viz*. carbon, nitrogen, boron, *etc*. Hydrazine, dimethyl hydrazine and the boranes are

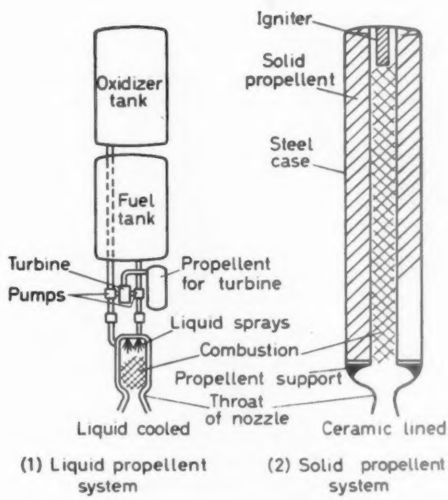

Figure 1. Two main types of rocket-motor

examples of some of the more recent fuels which have been studied extensively because of their use or potential value as high performance propellents. The light elements themselves, with the exception of

hydrogen, do not give a high specific thrust in spite of their high heats of reaction per unit mass. The reasons are that the temperature of combustion T_c is usually limited by the high enthalpy of vaporization of the oxide (or fluoride) and the mean molecular weight of the product gases may also be high, both reacting unfavourably on the value of $\sqrt{T_c/\bar{M}}$.

The theoretical specific impulses for a number of bipropellent systems have been calculated for chamber pressures of 1000 lb/in.[2] by the Theoretical

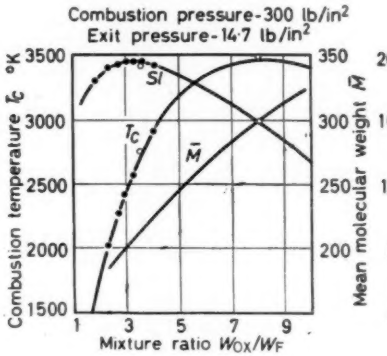

Figure 2. Relationship between SI and $\sqrt{T_c/\bar{M}}$

Chemistry Unit of Rocketdyne and a selection of their values is given in *Table 1*. The most widely used combination for long range rockets at the present time is liquid oxygen and kerosene, which under the conditions stated in *Table 1* has an optimum *SI* of approx. 280 sec.

Combinations which have a better performance are frequently termed high energy propellents although there is nothing unique about them. All have some disadvantage such as extreme reactivity, toxicity or scarcity *etc.* which has discouraged their use hitherto. It is worth noting however that the highest specific impulse for stable chemical substances is probably that given by liquid fluorine in conjunction with liquid hydrogen and approaches 400 secs. Liquid ozone as an oxidizer might be better with liquid hydrogen on account of the heat of decomposition which it can contribute, but in practice it has proved too unstable to be used with safety.

In theory, fuels composed of free atoms or free radicals would have a much higher performance than those listed in *Table 1*. These substances possess unpaired or 'odd' electrons which enable them to undergo highly exothermic chemical combination in order to achieve normal bonding. Intensive research at the National Bureau of Standards, Washington indicates however that the maximum concentrations of free radicals which can be produced and kept even at liquid helium temperatures are extremely low and hopes of obtaining a practical fuel of this kind have faded.

A great deal of interest and development work at the present time centres round the use of the stable high energy propellents like fluorine and hydrogen for the launching of space rockets. The relative merits of different systems with respect to a particular vehicle can only be determined after a full engineering assessment has been made but the curve in *Figure 3* indicates the effect of propellent performance (*SI*) on the take-off weight of a four stage rocket which can just achieve sufficient velocity to escape from the earth's gravitational field. The assumptions made in the derivation of this curve are given in reference 1. For a given payload small improvements in *SI* lead to substantial reductions in take-off

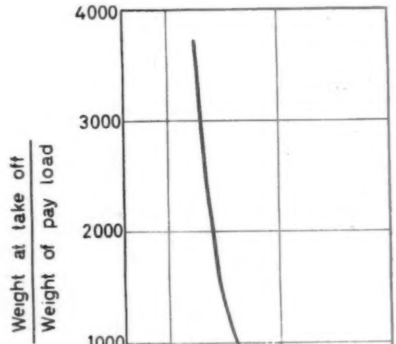

Figure 3. Dependence of take-off weight on specific impulse

weight and the designer must decide whether this advantage outweighs the disadvantage of handling a reactive and toxic oxidizer like fluorine.

Future developments in rocket propulsion beyond the atmosphere have been considered by L. R. SHEPHERD[2] who showed that even the high energy chemical propellents are inadequate for manned space flight to the moon assuming that the explorers

*Table 1. Theoretical performance of liquid propellent systems.**

Combustion chamber pressure = 1000 lb/in.² and nozzle exit pressure 14·7 lb/in.² Isentropic expansion is assumed

Oxidizer	*Fuel*	*Mixture ratio wt. oxidizer: wt. fuel*	*Chamber temp. °C*	*Mean molecular wt. of products at T_c*	*Max. specific Impulse lb/sec/lb (frozen equilibrium)*
Oxygen	Hydrogen	3·40	2415	8·9	388
	Hydrazine	0·74	3027	18·3	301
	Hydrocarbon (RP-1)	2·24	3282	21·9	286
	Diborane	2·3	—	—	340†
Fluorine	Hydrogen	4·54	2791	8·9	398
	Hydrazine	1·83	4218	18·5	334
	Diborane	6·33	—	—	330†
Hydrogen peroxide (95 per cent by wt.)	Hydrazine	1·84	2543	18·8	277
	Hydrocarbon (RP-1)	6·35	2613	21·6	266
Red fuming nitric acid (15 per cent NO_2)	Hydrazine	1·23	2727	19·7	277
	Hydrocarbon (RP-I)	4·10	2902	24·6	258

* With acknowledgments to Rocketdyne, a Division of North American Aviation Inc. † Values not attributable to Rocketdyne.

Note (1) RP-1 is a hydrocarbon fuel to U.S.A.F. specification MIL−F25576B

(2) Unsymmetrical dimethyl hydrazine (U.D.M.H.) is only slightly inferior in performance to hydrazine.

wish to return and that the initial weight of the rocket is not excessively large. Escape velocities can only be achieved by using multi-stage vehicles but what the optimum size for these will be eventually is not yet clear. The Russian Lunik rockets are reported to be 3-stage affairs weighing nearly 200 tons and no doubt bigger vehicles are envisaged.

Oxidizers

Although research on high energy propellents has received a great deal of attention, the development of the more conventional systems has not been neglected. It is usually the properties of the oxidizer which determines the choice of propellents and there are three of these in current use *viz.* liquid oxygen, hydrogen peroxide and nitric acid.

Liquid Oxygen

This is the most widely used oxidizer in ballistic and other large rockets. It has a relatively good performance with a number of different fuels (see *Table 1*) and is cheap and easy to prepare. It has the big disadvantage of a very low boiling point (−183°C) which means that it cannot be stored in closed containers and losses by evaporation are relatively high even in vacuum insulated vessels. Also the low temperature causes condensation of water vapour and the formation of ice which may lead to the malfunctioning of moving parts such as valves. Undoubtedly a number of mishaps to rockets using liquid oxygen can be attributed to this. Neither hydrogen peroxide or nitric acid give quite such a good performance as liquid oxygen but they have been preferred for certain applications particularly in rocket motors for aircraft.

Hydrogen Peroxide

Aqueous solutions containing more than about 70 per cent by weight of hydrogen peroxide are referred to as H.T.P. (High Test Peroxide) and concentrations of 85–90 per cent are now generally employed in rockets. These solutions undergo slow decomposition on storage because hydrogen peroxide is thermodynamically unstable and decomposition is accompanied by the liberation of a large quantity of heat.

$$H_2O_{2_{liq.}} \rightarrow \tfrac{1}{2}O_{2_{gas}} + H_2O_{liq.} + 23{\cdot}47\ \text{kcal} \quad \text{....}\ (1)$$

Many substances can accelerate this change and long term storage depends upon freedom from impurities (particularly catalytic ions such as manganese and iron) and upon the use of compatible materials for the containers. Modern methods of manufacture produce a very pure product with a high intrinsic stability but it is usually considered advisable to add a stabilizer. The most recent and effective of these is sodium stannate which is added in amounts up to 30 mg/l. Shortly after addition it undergoes a change and hydrated stannic oxide is precipitated in a colloidal form which

adsorbs catalytic ions from the solution and may possibly scavenge other suspended impurities during coagulation.

Adiabatic decomposition of H.T.P. (86 per cent) produces steam and oxygen at 650°C and is the reaction which is brought about with the aid of a catalyst when H.T.P. is used as a source of power. For rocket applications the catalyst must be of the least possible weight and volume and have quick starting activity and adequate life. Silver fulfils these requirements and its development as a catalyst is a good example of the way in which fundamental research can help the designer. The action of silver on H.T.P. was studied by F. T. MAGGS and D. SUTTON[3] who showed that the catalyst is first dissolved in the liquid with the formation of Ag^+ and HO_2^- ions. The rate of decomposition of the peroxide is low until $[Ag^+][HO_2^-]$, the ionic product, reaches a limit depending on the peroxide concentration. At this limit silver is reprecipitated in the form of very fine particles with an enormous surface area on which decomposition is greatly enhanced. Solution of the silver is a necessary step in the process but the initial state of the catalyst is also important because solution is diffusion controlled and the rate of solution is proportional to

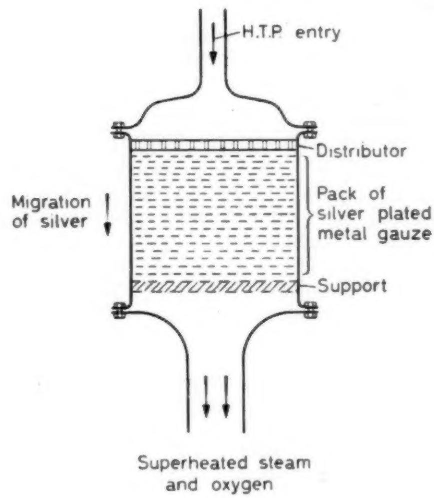

Figure 4. H.T.P. decomposer with silver catalyst

the surface area. Thus in a decomposer it is necessary to provide an adequate amount of silver in a suitable form for rapid solution at the head end or point of entry of the H.T.P. This can be achieved by using silver plated metal gauges arranged in layers as indicated in *Figure 4*.

For the main propulsion of a rocket, H.T.P. is used as one component of a bipropellent system, fuel being injected and burnt in the oxygen produced on decomposition. This system which is one of thermal ignition has certain advantages from the point of view of flexibility and safe operation. The decomposition of all or part of the H.T.P. is brought about in a decomposer placed before the combustion chamber and the hot oxygen and steam pass on into the latter where the fuel is injected. Spontaneous ignition occurs on account of the high temperature of the oxygen and normal combustion ensues. Precise timing of the entry of the fuel is not important and ignition by pyrotechnic or other means is obviated. Accumulation of unreacted propellents in the combustion chamber cannot occur and risk of explosion on starting is greatly diminished. This system is used in the British Black Knight research rocket and has been remarkably successful.

Nitric Acid

This was used in Germany as a substitute for hydrogen peroxide in rockets and since then has been used in America in the Aerobee sounding rocket and the Corporal Missile. It is also used in France's research rocket the Veronique. Several successful motors based on nitric acid have been developed in Britain also but have not found favour with the military authorities largely because of the unpleasant nature of this chemical. Nitric acid is very easy and cheap to produce however and is the only one of the three oxidizers in common use which can be sealed in a container. It is not entirely stable but red fuming nitric acid (R.F.N.A.) containing 15–18 per cent NO_2 and 2–2·5 per cent water reaches equilibrium between the liquid and gaseous phase at about 2 atm pressure.

One of the principal developments with this oxidizer has been the discovery that additions of up to 0·5 per cent of hydrofluoric acid greatly inhibit its corrosive action on metals like aluminium which can now be used for very long term storage of the acid.

Dinitrogen tetroxide is a related substance which gives very good performance as an oxidizer and can be stored but the temperature of operation with this substance is somewhat restricted.

Fluorine

Before leaving the subject of oxidizers mention should be made of fluorine since this compound figures prominently in high energy systems. The technology of production and handling of fluorine has developed enormously in recent years particularly

in the U.S.A., where liquid fluorine is now shipped in rail and road tankers. There is no doubt that it can be used in rocket systems and that experimental motors have been operated with it. The main objection to its use in the opinion of the author is not its reactivity but its toxicity and the toxicity of the HF which is the essential product of combustion. Hydrofluoric acid is non persistent in the atmosphere but readily absorbs moisture and produces solutions which are not easy to dispose of.

Fuels

A much wider range of fuels is available compared with the range of oxidizers and many, such as the hydrocarbons, are well known. Hydrazine and more particularly unsymmetrical dimethyl hydrazine $(CH_3)_2N.NH_2$ which is cheaper to prepare have attracted a good deal of attention because of their potential performance (see *Table 1*). The boranes and the alkyl boranes which have been the subject of an intensive research and development drive in the U.S.A. are not of great value for rocket propulsion and are not intended for that purpose. These compounds are extremely toxic and costly to produce and their performance in rockets can be equalled by other fuels.

Liquid hydrogen like liquid fluorine has received a great deal of attention and will sooner or later emerge from the experimental stage. Its very low density, 0·07 g/ml. is a disadvantage but not necessarily a serious one in the case of very large vehicles.

Combustion

Two of the principal characteristics of a rocket motor are the high rate of consumption of the propellents and the high intensity of the combustion which takes place in the combustion chamber. A modern liquid rocket motor such as that shown in *Figure 5* has a thrust of more than 100,000 lb and consumes propellent at a rate of over 40 gal/sec. It is a remarkable fact that this quantity of liquid is injected, atomized, vaporized and burnt in the relatively small space between the injector plate *A* and the throat *B*. The rest of the motor *B–C* is an expansion cone beyond the throat and not part of the combustion chamber. Until recently very little was known about the processes which take place in the chamber and little precise information was available for design purposes. The phenomenon of rough burning for example which in extreme cases can cause the mechanical failure of a motor is not properly understood. Attempts to rectify this situation are now being made and a number of experimental techniques have been developed for the study of gas flow, temperature and composition of the gases under the difficult conditions which prevail in the combustion chamber. The results of these researches will lead to better design data which in turn will mean not only better performance but improved reliability and safety of operation of the rocket motor.

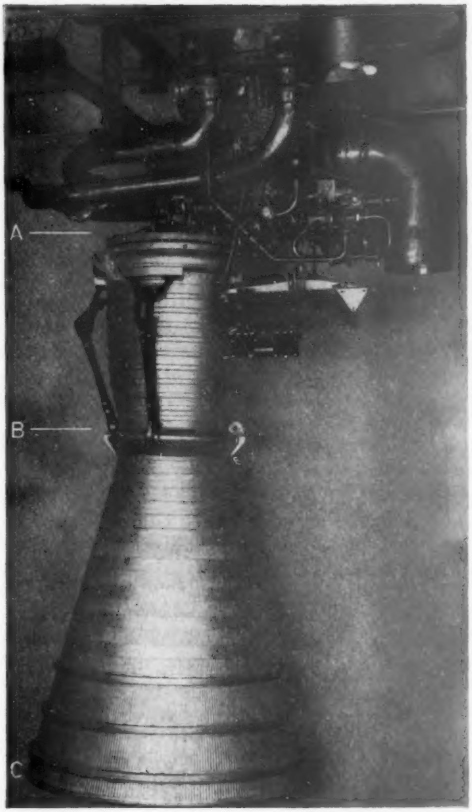

Figure 5. The Rolls-Royce rocket motor which will power the de Havilland blue streak long range ballistic missile. The engine has been developed by Rolls-Royce from the designs of the Rocketdyne Division of North American Aviation Inc. A, Injector or burner head; B, combustion chamber throat; C, nozzle exit. (Photograph kindly supplied by Messrs Rolls-Royce, Derby)

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SCIENCE IN PARLIAMENT

The Control of Radioactive Wastes

AT PRESENT disposal of radioactive wastes, with the exception of those from the United Kingdom Atomic Energy Authority, is governed only by legislation dealing with the disposal of ordinary domestic and industrial wastes. It is quite evident that due to the medical hazards of radioactive material this disposal should carefully be regulated. In 1956 a panel was appointed by the Radioactive Substances Advisory Committee at the request of the Minister of Housing and Local Government to investigate the nature and quantity of radioactive waste likely to arise, to recommend methods of disposal and to advise on any new legislation they considered to be necessary; the Radioactive Substances Bill, which was presented by Lord HAILSHAM and had its second reading in the House of Lords, is the result of the recommendations of this panel.

These recommendations have been published by H.M.S.O. (Command 884, The Control of Radioactive Wastes—November 1959), where the sources of radioactive wastes and the different means of disposal are discussed and analysed, always with reference to health hazards and genetic damage to the population. The panel concluded that it is economically necessary to carry on with certain activities that released ionizing radiations to the environment, but that this must be controlled within safe limits so that no member of the community should have his health endangered; that when assessing permissible levels of discharge other additions to natural background activity should be borne in mind, *e.g.* x-rays or fall-out, and that as there is a shortage of scientists trained in this field local control is impracticable and therefore the control should be on a national basis as a government responsibility, although the actual disposal might be carried out locally.

At the second reading in the House of Lords, the bill was described by Lord Hailsham. It provides for the compulsory registration of users of radioactive material, including those having mobile radioactive apparatus, and also that these persons must receive authorization before they may either dispose of or accumulate radioactive wastes. The Ministry of Housing and Local Government is responsible in England for the registration and for authorizing accumulations of radioactive waste, and, together with the Ministry of Agriculture, Fisheries and Food, for the authorizing of its disposal, and whilst the local authorities have no jurisdiction in these matters, they must be kept fully informed. As well as authorizing local disposals, the Ministers are to arrange for a national disposal service. The bill also deals with administrative matters such as the appointment of inspectors, the rights of applicants to be heard, offences, penalties, *etc.*

In the debate following Lord Hailsham's speech, Lord TAYLOR outlined the problems and methods of dealing with radioactive waste. It can be divided into three types, gaseous, liquid and solid waste. The first presents little problem as it can be blown into the atmosphere though, in some cases, it may have to be filtered and the residue treated as solid waste.

The liquid waste is of two types, low-activity high-volume and high-activity low-volume. The former is mainly used for cooling reactors and contains only short-lived isotopes which will release their radioactivity if stored, and it can then be delivered to rivers or into the sea, where its radioactivity is infinitesimal compared with the natural radioactivity in the sea; it may, however, be adsorbed onto mud, in pipes, on sludge at sewage works *etc.*, and these should be regularly monitored. The high-activity liquid is a greater problem: it can be permanently stored in tanks; it can be concentrated to solid waste, *e.g.* by heating with Montmorillonite clay to 1000°C to produce a hard rocky substance which absorbs nearly all the radioactivity and makes it perfectly safe and insoluble, or, in the case of ruthenium, it can be disposed of by fusion with glass or ceramic material. These are then treated as solids which can be dumped in natural impregnable quarries, sealed into a heavily constructed permanent box and dumped at great depths in the sea or buried. Lord Taylor pointed out that it was not generally speaking the large quantities of waste that were the danger, as these are now disposed of efficiently, but the small quantities, as the small users are likely to be more careless, and if their waste should become concentrated it would become an appreciable hazard.

Lord SHACKLETON and Lord MERRIVALE expressed concern at the dumping of radioactive wastes in the sea and Lord Hailsham drew attention to the statement by Dr GLUECKAUF of Harwell at the Monaco Conference that the 1966 British nuclear programme would give rise to 12 megacuries a year of Strontium-90 of which only 0·001 megacurie would find its way into the sea, whereas the natural radioactivity of the Atlantic Ocean, apart from fall-out from bombs, is 100,000 megacuries. No high-activity radioactive wastes are dumped directly into the sea, and the durability of the containers they are dumped in is related to their half-life.

SURVEY

Unmanned Power Station

The South Western Electricity Board has installed a small power station at Princetown on Dartmoor to bolster up the mains supply when it is heavily loaded and to act as stand-in in case of a mains break down. The generator, which is installed in a small building on the moor near Princetown, is completely unmanned and is controlled by signals transmitted over a G.P.O. public telephone line. Within two and a half minutes of the 'start' signal from Bristol the generator reaches its full load.

The Bristol Siddeley 3 MW turbo generator (*Figure 1*) was developed from the 4250 h.p. Proteus engine originally designed for the Bristol Britannia airliner and which has proved its reliability over nearly one million hours in airliner service. This engine is also used in the naval patrol boat 'Brave Borderer', the world's fastest warship*. The engine is a simple free turbine two-shaft unit without heat exchanger, only 9 feet long and 3 feet 6 inches in diameter. It is coupled to a 3200 KVA alternator manufactured by the Electrical Construction Company. A 110 volt battery is sufficient to provide current for the starter, the ancillaries which run before starting and to energize the solonoid for contact breaker closing. The servicing required by the engine is small; the filters should be inspected after every 100 hours of operation and a complete inspection made after 1000 hours.

The generator is regulated from the control room of the Bristol, Bath and Weston-super-Mare district of the South Western Electricity Board at Bristol, a hundred miles away from the plant. It operates through the public telephone exchange: when the engineer wishes to start, stop or modify the running of the generating plant he puts through a trunk call to the plant at Princetown. An automatic voice replies and after fifteen seconds the control engineer is able to transmit his instructions by the press-button method. The equipment is capable of carrying up to 40 different instructions and could be extended to control up to 24 sub-stations. When required technical information can also be relayed back from the generating station and information regarding, for example, megawatts, amps and volts recorded. If anything goes wrong at the generating station the engine switches off automatically, the automatic voice telephones the control room and by means of small lights the fault is indicated; this can then very often be corrected from the control room. At the plant there are also fire detectors and automatic fire extinguishers.

* See *Research* (1959), X, 361

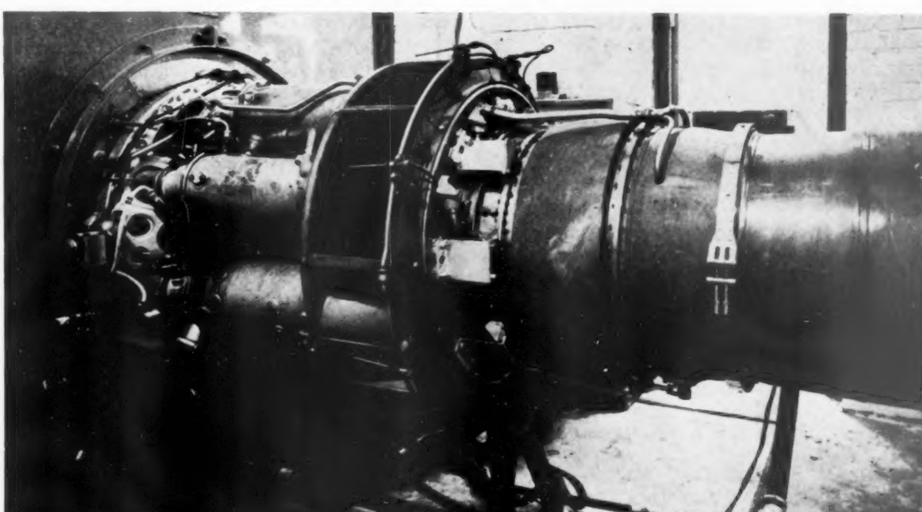

Figure 1. The power unit of the 3 megawatt turbo generator

The Post Office have given their approval to this apparatus but only for use by public utility bodies who employ a continuously manned control room. The apparatus, which is fully transistorized, was developed by Sound Diffusion (Auto-Thermatic) Limited.

The South Western Electricity Board expects this small generator to be used for short periods only and although the running costs are rather high the installation cost, compared with more conventional stand-by equipment, is low. The Board plans to erect a similar station in another stormy district, near Lynton, and if these two projects are a success they may be followed by others. The use of a small generator such as this appears to suggest a return to an old tradition, as the tendency in recent years has been for larger and larger plants serving wider areas, but when he opened the plant Mr C. R. King, the Chairman of the Electricity Council, emphasized that this generator in no way foreshadows a change in policy, as in most cases it is more economical to build either the large conventional or the nuclear power plants.

If run constantly, a generator such as this would be capable of supplying a town of 100,000 inhabitants with electricity and Bristol Siddeley say that they can make a turbo-generator six times as powerful as this one; indeed in many parts of the world their engines are already being used to generate electricity.

One very praiseworthy feature of this project was its speed of execution. Ministerial approval was received in April, 1959 and the plant was opened on September 11th, 1959.

Parliamentary and Scientific Committee Conversazione

On Wednesday 9th December the Parliamentary and Scientific Committee held a Conversazione at the Royal Society, Burlington House, the theme of which was *Science in Everyday Life*. A very large number of scientific and technological exhibits were displayed ranging from polio immunization to modern laundering techniques, from food to an automatic aircraft landing system, possibly the most dramatic item being the Marconi colour television unit.

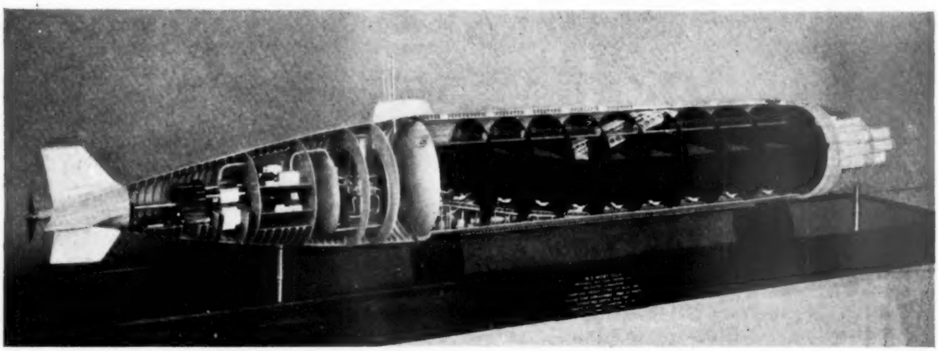

Figure 2. Model of 'Moby Dick' the Mitchell Engineering nuclear-powered submarine

An interesting exhibit was a model of a nuclear powered freight submarine (*Figure 2*) designed by Mr F. G. Mitchell of Mitchell Engineering Co. for the purpose of carrying iron ore from mines in Northern Canada, which are at present virtually closed down due to the difficulty of transport, the sea being frozen for most of the year. The submarine would be able to travel under the ice and surface through a specially cut hole. It would be capable of carrying 28,000 tons of iron ore having a displacement of 50,000 tons, speed 25 knots and an operating depth of 300 feet with a maximum diving depth of 600 feet. The length would be 607 feet and the diameter 72 feet. It would be operated by a Mitchell 150 MW (thermal) boiling water reactor, the delivered horse power being 50,000 at 120 r.p.m. Other cargoes could, of course, be carried, and it was suggested that the submarine could also be used to supply Royal Naval vessels at sea with oil, aviation fuel, ammunition, stores and relief crews.

Another interesting, but very different, piece of apparatus was the Master Vision Screener in the section on 'Optics and Vision in Everyday Life'.

It is designed for mass vision-testing in, for example, schools and factories. It can be operated by an unskilled technician and takes only a few minutes to test each subject. It is not claimed that it is a substitution for the optician but only that it is intended to discover optical defects which should then be further tested and treated by a qualified optician.

The Water Research Association had a very interesting stand on which they had an exhibit illustrating the coagulation process of water purification, in which aluminium sulphate is added to the water and coagulates out those constituents which cause colouration and turbidity. Apparently this system has been known and used since the bronze age, but is still not fully understood. They also showed an electronic leak-detector, which they admit is not so efficient as a skilled plumber but better than an unskilled one, and a selection of polythene and p.v.c. pipes. There are already about 3000 miles of polythene service piping in Britain and p.v.c. pipes are being tested for suitability for domestic use.

The section on animal health and food, which contained many interesting exhibits, included a veterinary display showing the improved health standard of the dairy herds in this country—93 per cent are tuberculin-tested as against less than 10 per cent in 1946, and mastitis has been virtually abolished. Some specimens of bronze age food, found at Jericho by the British School of Archaeology in Jerusalem, and said to be 4000 years old, were also shown; these were said to contain shrivelled meat fibres and when analysed chemically an appreciable amount of nitrogen compounds derived from the original protein was found. Vegetable tissue believed to be bread, and showing the thickened walls of millet, was also discovered.

The Hartley Hoister

Colonel Hartley, who during World War Two was concerned with the design of PLUTO (Pipe Line Under The Ocean), has now invented an apparatus designed to increase the off-shore loading and unloading rate of tankers where they are obliged to anchor some distance from land. At present the flow rate by the conventional underwater pipeline is about 2500 tons per hour as against 5000 to 6000 tons per hour at ports where there is direct loading or unloading at a jetty. Instead of rubber hoses the Hartley Hoister makes possible the use of wide steel pipes lying on the sea bed. These can be connected to the tankers by rubber hoses which are normally submerged but which are raised to the surface by the hoister when required.

The first Hartley Hoister has been installed at Kuwait. When not in use, the 96 feet long structure which carries the hoses lies flat on the sea bed, being anchored by chains at one end whilst the other end is held down by three buoyancy tanks containing a ballast of 50 tons of water. The rubber hoses are connected to the underwater steel pipes at the anchored end; at Kuwait there are three hoses running to a 24 inch steel pipe which is used for crude oil and a fourth hose to a 12 inch steel pipe for bunker oil.

When the pipe lines are required compressed air is pumped into the drums at the rate of 110 cubic feet a minute from a portable diesel-driven air compressor on a launch. In future installations

Figure 3. The Hartley hoister in action

air will be supplied from the shore through a submarine steel hose lying beside the oil pipes. The free end of the hoister carrying the rubber hoses rears up to the surface, the position of the centre of buoyancy being controlled so that the apparatus comes to rest at an angle of 70°—not vertically because it is desirable that there should be

a continual tension against the tanker to keep the rubber hoses taut so that they are pulled into a smooth caternary curve when coupled to the tanker, *e.g.* if the hoister reaches a vertical position there is a three ton pull on the hose. The depth of the sea at Kuwait is 56 feet so that 40 feet of the structure would be above the surface when vertical, and as it is anchored by chains it can sway in a 40 foot radius round its moorings, thus adjusting itself for movement of the tanker, due to wind, loading and unloading and rise and fall of the tide. The buoyancy tanks are so designed that they are always below the surface and therefore exert a continuous upward pull so that the hoister is not influenced by wave action. The rubber hoses are yoked together to facilitate handling, and connected directly to the manifold on the tanker (see *Figure 3*).

The Kuwait hoister takes approximately eighteen minutes to emerge which is about the time that it takes for a tanker to disgorge its ballast. Using this apparatus the flow rate of oil has been increased from 2650 to 3560 tons per hour, *i.e.* an increase of about a third, and only 90 feet of hose is used instead of 220–240 feet. The steel pipe is superior to hose as it requires less maintenance, has better flow characteristics and does not tangle or kink under water, and also the hoses which are carried by the hoister will not tangle or kink as they are always manipulated from the ends rather than from the middle.

The Hartley Hoister at Kuwait has been tailor-made for the conditions existing at that particular port. It could obviously be adapted for a very wide range of conditions in different parts of the world.

Telecommunications

COLIN CHERRY, Henry Mark Pease (Standard) Professor of Telecommunications, delivered his inaugural lecture in the presence of considerable noise from the building in progress at Imperial College. The Professor overcame these difficulties with marked success, and taking as his subject, *Telecommunication as a Social Science*, he showed that man is a necessary link in any communication system. Animals do not ' communicate ' but use a system of signalling and it is when man is by circumstances driven to adopting this system that he encounters difficulties. The motorist, for example, appreciates this.

The inclusion of human beings in a communication system results in the introduction of problems of man's making, both psychological and physiological. Professor Cherry reminded us that though we have two ears all communication systems assume the need for only one; he told us that the most common written word is *the* but that on the telephone the commonest word is *I*, showing how we are influenced by the medium we use.

Electrical and electronic communication comprises only part of this intellectually stimulating field and problems of semantics and psychology are but two of those which the communications engineer must include in his studies.

Boots' New Biological Research Centre

The new research centre which Boots have built in Nottingham is only one, though the largest, of a series of research units, Chemical and Biochemical, Antibiotic, Agricultural and Horticultural and Veterinary, which are congregated in or around Nottingham. This particular building houses the Pharmacological, Chemotherapeutic and Bacteriological Departments.

Much of the work in these laboratories deals with the testing of batches of drugs, insecticides, weed-killers, *etc.* to ensure that they are up to specification, and the development and testing of new drugs. The most basic research is going on in the Chemotherapy Division, on viruses, where protein synthesis, particularly of the flu virus, is being investigated; by studying the uptake of amino acids they hope to develop antagonists which will block protein synthesis and therefore reproduction of the virus. They are also making a particular study of tropical diseases in this department, working on new drugs for amoebiasis, schistosomiasis and trypanosomiasis. For the last they have recently developed a new prophylactic drug, prothidium, as a complement to their present, successful, therapeutic drug, ethidium. In the Pharmacology Division research is under way on non-hormonal anti-rheumatics, *e.g.* aspirin, the action of which is still not fully understood, and phenylbutazone.

Apparently the development of new drugs is still largely empirical, but as more biochemical research is being carried out in laboratories all over the world, the production of specific drugs is becoming increasingly possible.

CERN Proton Synchrotron

In the October/November 1959 issue of *Research* the first single-circuit trial of the CERN Proton Synchrotron at the CERN Accelerator Conference was reported. On Tuesday, November 24th the synchrotron reached its designed energy, 24 thousand million electron volts, for the first time, the full acceleration cycle sending the protons around the vacuum chamber for 480,000 turns (not 50,000 as previously reported).

BOOK REVIEWS

Introduction to the Theory of Quantized Fields

N. N. BOGOLIUBOV and D. V. SHIRKOV

(vi + 720 pp; 9¼ in. by 6¼ in.)

New York and London: Interscience. 128*s*

THIS BOOK gives an excellent account of quantum field theory. As might be expected from these authors, considerable emphasis is placed on the mathematical side with more attention to the mathematical rigour than is usual in this subject. However, the mathematics is presented with unusual clarity. This is achieved not by cluttering the book up with tedious details of the often heavy analysis but by stating precisely which mathematical operations are implied. The result is a book which, on the mathematical side, makes easier and more pleasant reading than many apparently more elementary accounts.

Nevertheless I would not call this book an introduction. No knowledge of field theory is presupposed but the physical interpretation of the mathematics is kept to a minimum and at times is inadequate. Consequently, the inexperienced reader must have great difficulties in appreciating the physical content of the theory or the reasoning behind some of the developments. For example, a more extensive use of the N-particle representation in discussing second quantization would greatly aid understanding. A later case of explanations which are all too brief is the treatment of gauge invariance of spinor electrodynamics. These examples are not meant as adverse criticisms in a book with a mathematical bias but are merely to show why it cannot really be considered as an introduction. Also, the approach is often quite sophisticated presupposing a knowledge of abstract general concepts; for example, the meaning of the irreducible representations of the Lorentz group.

The nine chapters cover the following material: chapters I to III develop the theory of free and interacting fields. Lorentz invariance, causality and unitarity rightly form the basis of an excellent development. In this way the scattering matrix is obtained directly in terms of the interaction Lagrangian and the uniqueness of this procedure is investigated in detail. On the more practical side, Feynman graphs are derived and applied to some processes, such as Compton scattering, in lowest order of perturbation theory. As the authors stress, these applications are only methodologically complete.

Renormalization questions are discussed in great detail in chapters IV to VI. The removal of divergence is carried out in chapter IV, while chapter V is devoted to particular theories, mainly electrodynamics. Chapter VI deals with bound-state problems. It seems a pity that the authors recoiled from the task of a complete account of the Lamb shift calculation, when well on the way to giving the first readable presentation.

The remaining three chapters deal with non-perturbation approaches to field theory. Chapter VII provides an introduction to the methods of functional integrals and uses these to obtain expressions in closed form for Green's functions. Chapter VIII develops the idea of the renormalization group and chapter IX gives an excellent, mathematically rigorous treatment of dispersion relations, based largely on Bogoliubov's own contributions. (The basic theorems in analysis are proved in an appendix especially written by Bogoliubov for the English edition.) It is a great pity, although not surprising in a rapidly developing field, that this chapter can no longer be considered up to date. In particular, the important investigations, by Dyson and others, of the analytical properties of vacuum expectation values are missing. No doubt, a second edition of this excellent book will appear in a few years in which these matters are brought up to date. Perhaps, if we start saving right away, some of us may be able to afford the second edition by then.

F. MANDL

Dendritic Crystallization

D. D. SARATOVKIN

(Translated from the Russian by J. E. G. BRADLEY*)*

(126 pp; 6 in. by 9 in.)

New York: Consultants Bureau; London: Chapman & Hall. $6·00; 50*s*

DENDRITES are the tree-like growths which are often found when a supercooled liquid solidifies or when crystals grow out of a supersaturated solution. In some way, rapid production of solid material occurs most readily at the sharp tip of a thin needle. So far, no satisfactory mechanism of dendritic growth has been proposed.

In this monograph the author reviews the conditions under which dendrites are observed. He suggests that in all cases the predominating factor in their production is the presence of minor impurities. He describes how growth at a point may be favoured with respect to that at a flat surface by quite small impurity concentrations. Much of the book is devoted to descriptions of the author's experimental work relating to his suggestion. The main fields are in the study of the effect of impurities on dendritic growth from solutions of salts and of contact fusion in metals and alloys. There is also a discussion of the application of his ideas to the mechanism of solidification of steel ingots. There are many good illustrations in the book, and several stereoscopic photographs (which can be examined easily with a simple stereoscope, the construction of which is described in the text) which are very effective.

The main defect in the book is its undue attention to empirical detail, which outweighs the treatment of fundamentals. But its value is that it covers a field not described elsewhere. The translation from the original Russian has been carried out adequately.

J. CRANGLE

Ferrites

J. Smit and H. P. J. Wijn

(*Translated by* G. E. Luton)

(*xiv + 369 pp; 9¼ in. by 6¼ in.*)

Eindhoven: Philips Technical Library. 72*s*

The progress made during the past two decades in the field of ferrites, *i.e.* ferromagnetic oxides containing iron as the major component, has been so rapid that the appearance of what is only the second book on the subject is extremely welcome. The authors, who are research physicists in the Philips Laboratories at Eindhoven, have themselves made substantial contributions to the present knowledge of ferrites. They are therefore particularly well qualified to write this book.

The book is divided into four parts. *Part A* contains six chapters which deal with the fundamental theory of magnetism without resort to rigorous theoretical treatment. The last three chapters devoted to magnetic anisotropies and magnetization processes cover these complex fields with particular clarity. *Part B* consists of a single chapter in which is discussed methods of measuring magnetization, magnetocrystalline anisotropy energy, magnetostriction, the complex initial permeability in various frequency ranges and loss phenomena. Much useful information is collected in this chapter, but the accent is not always on the practical aspect of the measurements. *Part C* is devoted to a discussion of certain intrinsic properties (crystal structure, saturation magnetization, crystal anisotropy, ferromagnetic resonance, *etc.*) of ferrites having the spinel, garnet and certain hexagonal crystal structures. The so-called *Ferroxplana* compounds, where the the crystal anisotropy lies either along or perpendicular to the hexagonal axis, are discussed in great detail. By comparison, the very interesting and important group of rare earth ferrites having the garnet structure are dismissed in less than four pages.

The last part of the book contains six chapters dealing with physical properties of synthetic polycrystalline ferrites. The first chapter discusses various aspects of the structure of polycrystalline ferrites and includes a short account of their preparation. This is not detailed enough, however, to be of much help to anyone who has no previous experience of preparing ferrites. The rest of *Part D* is taken up with a very clear account of d.c. and a.c. electrical properties, static initial permeability, the frequency dependence of initial permeability, hysteresis loops and dynamic properties at high field strengths: these topics are treated very fully in the main and this section is probably the most important part of the book.

In an attempt to cover a wide range of subjects there is a certain amount of unbalance in the presentation. This arises in part from the fact that the authors have placed considerable emphasis on work carried out in the Philips Laboratories. For example, whereas some 1959 'Philips' work on conduction in cobalt ferrite is included, other less recent advances—such as the evidence of an antiferromagnetic transition in zinc ferrite, or the work of Kreissman and Harrison on the distribution of metal ions over octahedral and tetrahedral sites—receive no mention. The authors claim however that the book is not exhaustive as regards the subject matter and that the selection of the material is governed by their own special preferences and viewpoints. While this does not seem entirely satisfactory, in view of certain notable omissions, the material that is included is for the major part extremely well presented. Certainly the above criticisms do not prevent the book from being a most acceptable addition to the literature on ferrites.

The book contains 244 figures and photographs which are of the highest standard. Something over 250 references are arranged in such a way that the list acts as a very effective author index. L. C. F. Blackman

Free Radicals as Studied by Electron Spin Resonance

D. J. E. Ingram

(*ix+274; 8¾ in. by 5½ in.*)

London: Butterworths Scientific Publication; New York: Academic Press. 50*s*; \$9·50

An unpaired electron may be regarded as a small magnet pointing along the spin momentum vector of the electron. A number of such electrons, placed between the poles of a magnet will orient so that their moments lie along the field, strength H, though a very few by absorbing thermal energy point against the field. According to quantum theory, an electron spin can only have these two orientations, differing in energy by a definite amount $g\beta H$, where β is the Bohr magneton and g a constant, about 2. If the liquid on solid specimen containing the free electrons is therefore in a steady magnetic field, and also inserted in a wave guide, electromagnetic energy $h\nu$ may be supplied at a definite frequency corresponding to the dimension of the wave guide. Then by adjusting $g\beta H$ to equal $h\nu$ a resonance condition may be reached when electromagnetic energy is absorbed from the wave guide to bring more electrons with the anti-field condition. It turns out that the value of H for resonance, *i.e.* the g value, the width of the absorption line, and its hyperfine structure give considerable information about the unpaired electron and its neighbouring atoms. The method therefore gives information on the structure and concentration of free radicals, which form labile intermediates in many chemical reactions.

The present book gives an admirably clear account of the subject at the right level of interest for physical chemists. It opens with a general account of free radicals and then goes on to an adequate and very clear description of the practical aspect of electron resonance measurements. So far the electron spin resonance spectrometer has been used to investigate stable free radicals, and radicals produced by irradiation. A discussion of the ultimate sensitivity of the instrument, which is given, is therefore of great interest in connection with possible applications in thermal free radical reactions. It then goes on to a series of chapters on the different aspects of free radicals, such as stable free radicals, irradiation, polymerization, biradicals etc. and ending with biological and medical applications. These chapters are authoritative and contain full references to the literature. To take

only one example, there is a list of solid free radicals and relevant resonance data which the reviewer has found invaluable. There is no doubt that the book will stimulate further work and can be recommended to all research workers in the free radical field. Resonance methods as a whole form probably the most important addition to physico-chemical methods that has been made since the war. The lucidity and easy style of this book enables one to recommend it without reserve to all chemists who wish to gain some general knowledge of one of the most important of these techniques. D. D. ELEY

Free Radicals: An Introduction

A. F. TROTMAN-DICKENSON (1959)

(*vii+182; 6¾ in. by 4½ in.*)

LONDON: Methuen. 12*s* 6*d*

THIS book is concerned mainly with free radicals as intermediates in chemical chain mechanisms, so that to some extent it is complementary to Professor INGRAM'S volume reviewed above. After the introduction two brief chapters deal in a succinct fashion with the production and properties of free radicals. Thereafter chapter 4, the main part of the book, deals with reactions of monoradicals, and a short fifth chapter on biradicals completes the work.

The book as a whole forms a useful survey for honours students and budding research workers, with certain qualifications. Chapter 4, in particular, rather has the character of a running review of recent work. The Ogg and Polanyi potential curve method is used at several places to systematize results but one is left with the feeling that an initial chapter dealing with this method and transition state and its applications to radical reactions would have considerably aided subsequent discussion. However, the field is one undergoing vigorous development, so perhaps such a treatment is too much to expect at present. As for biradicals, this topic is advancing even more rapidly, and no doubt it will soon merit a monograph in its own right. At several points in the work the author draws attention to the power of gas chromatographic methods, which have given a new lease of life to the experimental side of gas kinetics. Clearly something similar is called for on the theoretical side. The book forms a useful addition to the pocket literature of chemistry. D. D. ELEY

Gmelins Handbuch der Anorganischen Chemie Magnetische Werkstoffe. Iron

(*Part A, Section 2, 8th Edn. Suppl. 1958, System No. 59*)

(*xxxviii+580 pp; 10 in. by 7 in.*)

Weinheim: Verlag Chemie. 326 D.M.

THIS volume follows the same pattern as the first supplement which appeared in 1936, consisting of short abstracts, arranged by subjects, of the publications on the research work carried out in this field in recent years. In the main the layout is the same as in the earlier volume, though two alterations are worthy of mention. The table of contents is duplicated in English, whilst throughout the text the paragraph headings are also translated marginally into English.

The first thirty odd pages are devoted mainly to an account of the theories of ferromagnetism, including ferrimagnetism, domain theory, the theory of the magnetization curve, *etc*. Of necessity this is heavily condensed, but it constitutes a useful introduction for the non-specialist in magnetism to the material data which follows, though the relative space devoted to the competing theories is perhaps somewhat unexpected.

This is followed by a section on the ferromagnetic elements and their alloys, comprising well over half the rest of the book. The dependence of magnetic as well as the electrical properties of the magnetic elements on a wide variety of physical parameters is covered in comprehensive fashion, followed by similar data for alloys, including those with many components, which are dealt with according to their importance. The ferromagnetic alloys of manganese and chromium are also included.

After a brief summary of the permanent magnet alloys an extensive section deals with the new oxide magnetic materials. This covers not only the ferro spinels but also the complex ferromagnetic oxides. This section will be particularly welcomed by workers in this field, though it is a pity that the garnets, and in particular the rare earth garnets, do not receive better coverage; however in extenuation it may be said that many of the papers are too recent to be included, though there are some references to 1958 publications. The final section is a bibliography of relevant patents.

This reference book will be a welcome library addition, though its price will probably put it out of reach for many research workers. Apart from the one or two omissions mentioned, it gives a remarkable coverage of the last twenty years progress in magnetic materials and their properties and as such can be recommended to all those interested. W. SUCKSMITH

Masers

GORDON TROUP

(*x+168 pp; 6¾ in. by 4½ in.*)

London: Methuen. 13*s* 6*d*

THE ADVENT in recent years of the Maser and other low noise devices is having a profound effect on microwave techniques. Consequently an interest in the book under review can be expected from microwave engineers as well as from physicists, to whom the Maser represents an extension of knowledge relating to the interaction between radiation and matter. The latter topic, treated from the stand-point of thermodynamics and quantum theory is covered in the initial chapters and it is shown that essential for Maser action is a population excess in the higher of two energy states. Methods of achieving this distribution are then discussed, as applied to gaseous, two-level and multi-level solid state Masers. Succeeding chapters deal with the theory of the performance of travelling wave and resonant cavity circuits, using such active material, to provide extremely low noise amplifiers or very stable frequency oscillators. This is followed by a review of experimental work and future possibilities.

The book is good value at a very reasonable price and comprises an adequate balance between basic theory and experimental practice. There are a few minor errors, not sufficiently important to detract from the value of the book. However the reviewer does take exception to a definition of noise factor which, under certain circumstances, leads to a deterioration of noise factor consequent upon an improved performance, (p. 85). (Unfortunately this type of confusion is not limited to this particular book, and can be eliminated only by using a different concept, such as excess noise temperature, to define noise performance.) Some sympathy is due to the author for what seems a long lapse of time between his original treatise of January, 1958 and the date of publication in Autumn, 1959, particularly in the context of the rapid changes in this subject. Notes have been added in proof to partially offset this and they are mainly concerned with advances made in experimental techniques. This book should appeal to quite a wide range of readers and is to be recommended. C. R. DITCHFIELD

Soviet Research in Fluorine Chemistry 1949-1956 (Parts I, II and III) (*English Translation*)

(*429 pp; 10¾ in. by 8½ in.*)

New York: Consultants Bureau Inc. $45 ($15+$20+$20)

THIS work is a collection of English translations of original papers on various aspects of fluorine chemistry, which appeared in Russian journals from 1949 to 1956. The collection is not a complete record of Soviet publications in the field in this period since not all journals are translated, but it is, nevertheless, a most useful compilation.

Part I consists of a varied collection of 23 papers on Organic Fluorides and Fluorocarbon Olefins. Topics covered include: the use of alkyl fluorides and of silicon tetrafluoride in Grignard syntheses; syntheses of aromatic and heterocyclic compounds containing trifluoromethyl groups and also isolated fluorine atoms; the preparation and properties of 1-chloro-2-fluoroethane; the reactions of fluoroprene. Some of the papers on the addition reactions of fluoro-olefins which have recently been published by Knunyants and co-workers are included.

Part II is concerned with inorganic fluorides and analysis. The inorganic section contains 17 papers on various metallic fluorides, chiefly those of the alkali metals, alkaline earth metals, lead and aluminium, and including complex fluorides. The section on analysis has six interesting papers including three on analysis of fluoro-organic compounds.

Part III deals with the chemistry of hydrogen fluoride, boron trifluoride and the etherates and fluoroborates. There are eight papers on reactions of hydrogen fluoride, both with organic and inorganic materials. The fourteen papers on boron trifluoride are mainly concerned with its varied uses as a catalyst in organic chemistry. Four papers in the final section describe different aspects of fluoroborate chemistry.

These three volumes are most useful to English-speaking chemists interested in fluorine compounds. Russian work in the field is of increasing interest and importance, and to have their papers collected and translated is a very useful service. To be of most value, however, this should be done fairly frequently so that the papers in each issue are recent ones. Though the price of the present work is high, it will be useful to all centres of fluorine chemistry in English-speaking countries.

J. C. TATLOW

Theoretical Elasticity and Plasticity for Engineers

D. E. R. GODREY

(*x+311 pp; 10 in. by 6¼ in.*)

London: Thames and Hudson. 42*s*

THIS is a somewhat unusual book. Its title may suggest that it is a formal treatise, but in fact this is not so and its aim appears to be rather to fill in gaps in the knowledge of the graduate engineer than to present him with a coherent picture of fundamentals. For this reason it is not suitable as a primary text book for those students who are unfamiliar with the elements of this important field of study, but it could be valuable to the graduate engineering scientist who must consolidate and supplement his acquaintance with the subject in order to tackle successfully some novel problem in research or development.

In the main, the book is written from the standpoint of the applied mathematician and the problems at the end of the chapters, though useful, might have been made more attractive to the engineer if some, at least, had been more closely related to specific examples occurring in engineering practice. The author has very wisely provided worked solutions for these problems, and not simply the answers, and has in addition included appendices dealing briefly with certain mathematical methods which may be unfamiliar to the reader or which he is likely to find difficult. Nevertheless, the mathematical knowledge required for the book as a whole ought not to overtax the capacity of the honours engineering graduate.

As might be expected, by far the greater part of the book deals with elastic theory and only three chapters are devoted to plasticity. These chapters are, on the whole, well done, but the introduction to chapter X, on the Theory of Plasticity, has been rather skimped. It may be noted that the material on plasticity relates to perfectly plastic bodies, that is, with no work-hardening, and provides solutions to some of those problems which are reasonably tractable mathematically.

To sum up, whilst the book may not satisfy the specialist, it may well prove a useful tool in the hands of both mechanical and civil engineers engaged in design work, and as such is to be recommended. It is clearly written and well printed and illustrated, and the author very sensibly gives at the end a complete list of the symbols used in the text. L. J. KASTNER

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